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OBSERVATIONS OF MARS AT THE OPPOSITION OF 1924

BY

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The general program of the Lick Observatory for observations of *Mars* at the opposition of 1924 consisted of two parts. The first, a color survey of the planet through photography by light of different colors, was undertaken by Mr. Wright with the Crossley reflector and his results have already been reported upon.¹ The second part, which forms the subject of the present publication, is based on photographic and visual observations with the 36-inch refractor and is accordingly restricted to the small region of the spectrum within which this telescope functions effectively.

At first the program was to a certain extent experimental in character, in order to compare the relative merits of the photographic and visual method of observation. When many of the photographs were found to be of good definition showing a considerable amount of surface detail, the observations were regularly continued. The ease with which micrometric measures can be made on photographs suggested the utilization of the plate material not only for descriptive purposes but also for obtaining accurate areographic longitudes and latitudes of numerous markings and for the determination of some of the constants such as the diameter and flattening of *Mars* and the position of its axis of rotation. A preliminary account of the observations was given in the *Publications of the Astronomical Society of the Pacific* (36, 263, 1924).

1. THE OBSERVATIONS

While most planetary photographs so far have been obtained with an enlarging apparatus in the telescope, the long focal length (58½ feet, 17.6m) of the Lick refractor made it possible to take the photographs

directly at the focus of the objective. A photographic attachment was accordingly constructed at the workshop of the observatory comprising a double slide plateholder for 4x5 inch plates. With careful rating of the clock no guiding was necessary during the short exposures (1.5 to 20 seconds), but the sliding plateholder was convenient for making a large number of exposures (40-50) in rapid succession on the same plate, shifting the plate slightly between the exposures.

The Lick objective, being designed for visual observations, has a good color correction only for yellow and orange light (minimum focus at 5700 Å.). It is necessary, therefore, to use plates sensitized to yellow light and to insert a color filter a short distance in front of the plate to exclude the light of short wavelengths. As the focal image of *Mars* in the 36-inch refractor is a disk of only 2.2 mm. in diameter or less, a fine grain of the plate is of prime importance, and it is further desirable that the plate should have a high degree of contrast in order to bring out the more delicate shadings. Trying several commercial brands of plates, Seed process plates were found most suitable for this work, and they were sensitized to the yellow and orange by bathing in a solution of Pinaverdol according to the instructions of the Bureau of Standards. It is a remarkable fact that these plates, very slow in ordinary photographic work, gain in speed when sensitized to the longer wavelengths. With a yellow filter they required only about twice the exposure time of the fastest commercial orthochromatic plates, while they are far superior in grain and contrast. The plates were developed for 60 seconds with Rodinal developer 1:5 at a temperature of 70° F.

Two different color filters were used. The Flavazine T filter (No. 16 in the Wratten light filter catalogue

¹ *Publ. A. S. P.* 36, 239, 1924; *L. O. Bulletin* 12, 48, 1925.

of 1922 of the Eastman Kodak Co.) is in the following designated as yellow filter. When its absorption is combined with the color sensitivity of the plates, only wavelengths between about 5300 and 5900 Å. are effective and the photographs are practically monochromatic. Wright's observations with the Crossley reflector showed that photographs of *Mars* taken in infra-red light produced greater contrast between the dark markings and the normal surface and would be more advantageous for the study of surface details. Although a refractor is not suited for infra-red photography, some advantage at least might be gained by using the visual red. A filter of red selenium glass, designated in the following as red filter, combined with the same plates utilizes light of the wavelengths 5900 to 6100 Å. and its use resulted in an appreciable increase of contrast, while the chromatic aberration of the objective is not yet sensible in this region of the spectrum. In the later part of the work most plates contain exposures taken with each of the two filters. The yellow photographs required an exposure of $1\frac{1}{2}$ to 2 seconds, the red ones 15–20 seconds. The focus setting of the telescope was determined visually with an eyepiece for every plate and the different exposures of a plate were distributed among 4–5 focus settings varying within a range of about 2 mm.

A few trials were also made to enlarge the image of *Mars* in the telescope with a negative lens placed about 6 inches before the plate (enlargement $2\frac{1}{2}$ times). Fig. 2 on Plate I reproduces the best of these photographs. As a rule the enlarged images did not show more detail and often less than the direct photographs taken on the same night, while the longer exposure and smaller contrast are decided disadvantages.

When time was available between the sets of photographs, the telescope was used for visual observations resulting in 37 drawings or sketches made with magnifications 270, 350, and 520. Most of these, however, are incomplete and were intended only to supplement the photographs and to record some of the more difficult details. A few complete drawings, prepared partly from photographs, partly from visual sketches made on the same night, are published in the *Publications of the Astronomical Society of the Pacific* (36, 263, 1924) and in *Popular Astronomy* (34, March 1926). As the Lick refractor is not provided with a diaphragm, all observations, visual and photographic, were made with the full aperture of 36 inches.

The quality of the photographs depends in the first place on the steadiness and homogeneity of our atmosphere, the so-called "seeing." On a few nights the seeing was too poor to attempt any photographic or visual observations of *Mars*. Most observations were made with fair (average) seeing, when some unsteadiness in the images was noticeable with magnification

270, on a few nights the seeing could be classified as good, but in no case were the conditions so perfect as to give sharp and steady images with magnification 520. Undoubtedly the great zenith distance of *Mars* (55° – 65°) was to some extent responsible for this difficulty. It should be kept in mind, too, that the use of the telescope had to be divided among several observers and that the instrument was available only for a limited number of observing periods fixed in advance.

While the visual observer has to watch the ever changing, moving, blurring or distorting image for the moments of best definition in order to catch the finer details, the photographic observer has to rely on a great number of exposures for obtaining some photographs of good quality. On the other hand one exposure falling on a moment of best definition furnishes a whole picture; it can be studied afterwards with every care and may yield much more information than the visual observer could have gathered in that short moment. The percentage of good images among the 40–50 exposures taken in rapid succession on the same plate varies greatly with the seeing. Even on nights with only fair or average seeing quite good photographs are sometimes obtained, but they will be rare among a large number of worthless ones. Every plate was therefore first examined with a magnifying glass, and the best images were marked for further study. It is very rare that among the selected images of a plate one stands out as the best showing every detail visible on any of the others. As a rule it is found that one image shows one region to best advantage, while other images give better definition for other markings, and a comparison of three or four selected images will reveal considerably more detail than a reproduction of any single one.

This situation is often overlooked when judging the merits of photography for planetary description. Photographs are most desired for the purpose of direct reproduction and publication, and undoubtedly they have considerable value in this respect. But it must not be thought that reproduction of a few of the best images can exhaust the information contained in a series of photographic observations. In the first place, the finer details are so delicate that it is practically impossible to bring them out fully in reproductions. In the second place, it lies in the nature of telescopic seeing that in general no single image shows all details in best definition and that the results have to be gathered from several photographs by the laborious process of comparison. In the third place, many of the finer details, especially some of the so-called canals, are so faint and elusive that at a superficial examination they are overlooked or attributed to the grain of the plate; only a careful comparison of different images

can convince the observer of their reality and at the same time allow him to eliminate the effects of the plate grain as well as distortions due to the seeing. With the photographic method then the main work lies in the examination and comparison of the original photographs, and the results of this work can be adequately presented only by drawings. It was therefore decided to construct a chart of *Mars* reproducing as faithfully as possible the appearance of the photographs and combining all the details which seem to be real on account of repeated visibility.

During the opposition of 1924 about 1700 photographs of *Mars* were obtained. About 150 or 9% of these were found to be of some value for descriptive purposes, and it is of interest to note that the collection of best images on which our chart is essentially based represents a total exposure time of only 15 minutes. Plates I and II reproduce 24 of the best photographs. In order to minimize the loss of detail in the process of reproduction a rather great enlargement (12 to 18 times) was chosen, and the fainter canal-like markings may be somewhat better visible if the plates are viewed from a distance of 2 to 3 feet, when the grain becomes less disturbing. With each figure the longitude of the central meridian (λ_0) and date of observation are given, while the letters y and r indicate whether the photograph was made with the yellow or red color filter. Those of Fig. 1 and 3 of Plate II were taken on Seed 23 plates used in the earlier experiments; they show plainly the coarser grain. The image of Plate I, fig. 2 was enlarged in the telescope as already mentioned.

2. MEASUREMENT OF THE PLATES

Accurate areographic longitudes and latitudes of numerous markings were needed in order to give the chart correct proportions, and it was thought that such data would also have a value in themselves as a basis for the discussion of seasonal and progressive changes in these markings. For this purpose the original negatives were measured in rectangular coordinates with the double micrometer of the eyepiece of the Repsold measuring engine. The microscope was adjusted for a magnification of 11 diameters which corresponds to about 800 for the combined magnification of telescope and microscope. A pencil sketch of the appearance of the image was first made showing every detail visible. All points sufficiently well defined were then bisected with the vertical and horizontal wire in turn and their identification numbers entered on the sketch. Settings on the edges of the disk were made at the beginning and end of the measures of each image. As a rule four images were selected on every plate.

At first (Winter, 1924-25) 13 plates with well distributed central meridians, all taken near opposi-

tion, were measured as completely as possible. These measures were made through the glass, so that the images appeared as seen in the refractor. On seven plates two images were measured in "direct" position (South polar cap at top), two images in "reversed" position (South polar cap at bottom), while on the remaining six plates all images were measured either in the direct or the reversed position. Reducing the measures to the center of the disk as zero point and expressing them in fractions of the planet's radius, rectangular coordinates were obtained with the y axis parallel, the x axis perpendicular to the polar axis, and the results of the four images of the same plate were combined to a mean. As a first approximation the polar cap was used for the orientation of the images. The longitudes and latitudes were then calculated with the data of the *American Ephemeris* and orientation corrections applied as derived by comparing the overlapping parts of the different images. Most of the better markings had been measured on 3-5 plates, and by combining these results with appropriate weights a preliminary catalogue of areographic longitudes and latitudes was formed.

Full benefit of the accuracy of photographic measures of Martian markings can only be gained, if the constants needed to convert the rectangular coordinates into longitudes and latitudes are sufficiently reliable. This did not seem to be the case and a new determination of these constants from the photographs themselves had to be undertaken. It seemed especially doubtful, whether the settings on the edge of the disk would give the diameter of the solid surface to be used in the reduction. This last question had been raised by Wright's work, which proved that the apparent diameter of the photographic image of *Mars* varies considerably with the color in which the photographs are taken; violet or ultraviolet images have larger diameters than red or infra-red ones. This fact suggested that the visible limb of *Mars* does not always correspond to the solid surface of the planet, but rather to a certain layer of its atmosphere; different colors including more or less of this atmosphere. It seems then likely that the generally adopted value of the diameter of *Mars*, derived from visual measures of the limb, is affected in a similar way, and the question: what is the true diameter of the Martian surface? at once gains a new interest in itself, aside from its importance for the reduction of the measures.

Wright² describes a method for determining this quantity which was employed, with some modifications. On account of the rotation of *Mars* the surface markings appear to be slowly moving across the disk. A series of photographs taken at regular intervals during a period of 6-8 hours in the same night will furnish a

² *Publ. A. S. P.* **36**, 252, 1924.

large part of this apparent elliptical path for certain markings. If a well defined point near the equator is selected and measured on all the exposures, the complete ellipse of its path can be constructed with the aid of the times of the exposures and the known period of rotation. The major axis of this ellipse gives the diameter of the solid surface, while its orientation and excentricity determine the position of the axis of rotation. Since the period of rotation of *Mars* is very accurately known, it is not necessary to take all the exposures on the same night. It may even be preferable to combine the best photographs of different nights, as it is difficult to obtain a long series of observations on the same night under uniformly good atmospheric conditions, and the low altitude of *Mars* at the 1924 opposition made a sufficiently long observing period impossible.

As very few changes in the markings were noticed during our brief period of observation, it seemed desirable to utilize all successful photographs for the application of this method, and it was decided to determine at the same time the diameter of *Mars* from settings on the limb so as to obtain a close comparison between the two methods. Forty plates, altogether, were found suitable in quality, and their measurement was undertaken in the summer and autumn of 1925 with the same apparatus as described above. This time, however, the plates were measured film-side up, and great care was taken to prevent any changes in the adjustment of the microscope during the whole period. The position angle of the polar axis to which the plates were oriented was taken from the *American Ephemeris*. Four images were again selected on most plates. The settings on the limb were made at the endpoints of the polar and equatorial diameters; they were repeated for each image in four positions of the plate; for the markings, one image was measured in each of the four positions. In this second series of measures no attempt was made to include all markings visible, as the preliminary measures of 13 plates had already given a sufficient number of reference points for the chart. The measures were confined to three classes of markings:

1. Points on the outline of the polar cap and details in its immediate surroundings.
2. Six to ten well defined points each, near the eastern and western limb of the planet and situated not very far from the equator. Such points of course are of greatest weight in the determination of the diameter and of the position angle of the axis of rotation.
3. Any marking appearing in exceptionally good definition or of unsatisfactory weight in the preliminary catalogue.

Many points on the 13 plates of the first series were thus remeasured, and this made it possible to reduce

the results of the first measures to the more homogeneous system of the second measures by appropriate zero and scale corrections applied to the rectangular coordinates.

3. SCALE VALUE AND ZERO POINT OF POSITION ANGLE

When the *Mars* photographs were taken it was not anticipated that they would be used for such extensive measures, and no provision was made at the time to furnish the scale value and position angle orientation of each plate. These two constants had therefore to be determined from photographs of wide double stars taken during the following summer (1925). For the scale value, which varies very little for focal images of a large refractor and has to be known only with an accuracy of 1 part in 1000, this method seemed perfectly justified. Some doubts were, however, entertained at first, whether the position angle orientation of the plate would remain sufficiently constant. While plate and plateholder could not appreciably change their position relatively to the camera attachment, it was necessary to investigate whether the latter, when screwed in at the end of the telescope, would always stop at the same point. The double star observations of 1925 made in exactly the same way as the *Mars* photographs, however, dispelled all doubts on this point and showed that even over a period of five months no changes in position angle orientation of more than a few tenths of a degree occurred.

The double star photographs were measured interspersed among the *Mars* photographs, each image being measured in the four positions of the plate. The results are tabulated in Table 1. The number of the pair in the first column is that of Burnham's *General Catalogue*, the adopted position (apparent) in the second and third columns was kindly furnished by Dr. Aitken from the best recent measures of double star observers. Only for B.G.C. 7018 these data were calculated from Boss's *Preliminary General Catalogue*, which gives the positions of both stars. For this pair the distance was too large for direct measurement with the micrometer and was subdivided into intervals of 40"-50" by fine lines drawn with a needle on the film. After the date of the photographs (5th col.) and the temperature (6th col.) during the observations follows the number of images measured on the plate and their quality (g=good, f=fair, p=poor). The last three columns contain the correction to the position angle reading of the measuring engine, the value of a screw revolution (mean of both screws, there is no appreciable difference between them), and the weight adopted for each result of the screw value. The latter was chosen according to the separation of the pair, the accuracy of its adopted position, the number and quality of the images measured. For the position angle cor-

Fig. 1. $\lambda_0 = 5^\circ$, Oct. 11, *y*. Fig. 2. $\lambda_0 = 12^\circ$, Oct. 12, *y*. Fig. 3. $\lambda_0 = 12^\circ$, Oct. 12, *y*. Fig. 4. $\lambda_0 = 13^\circ$, Sept. 4, *y*. Fig. 5. $\lambda_0 = 37^\circ$, Sept. 2, *r*. Fig. 6. $\lambda_0 = 44^\circ$, Aug. 31, *r*. Fig. 7. $\lambda_0 = 64^\circ$, Aug. 28, *r*. Fig. 8. $\lambda_0 = 70^\circ$, Aug. 29, *y*. Fig. 9. $\lambda_0 = 89^\circ$, Aug. 26, *y*. Fig. 10. $\lambda_0 = 92^\circ$, Aug. 28, *r*. Fig. 11. $\lambda_0 = 128^\circ$, Aug. 24, *y*. Fig. 12. $\lambda_0 = 130^\circ$, Aug. 22, *y*.

TABLE 1
POSITION ANGLE CORRECTION AND SCREW VALUE

B.G.C.	Adopted position 1925 Pos. A.	Distance	p.E.	Date of obs. 1925	Temp. C.	Images measured	Corr. to Pos. A.	Screw value 1 revol.	Weight
6212	271.1	20.26	±.05	July 1	+20.0	3 p	-3.1	5.923	0.5
7018	314.3	230.98	.08	May 22	+11.5	4 f	-3.7	.887	2
8914	103.5	22.10	.05	July 18	+24.7	6 g	-3.0	.896	1
9005	208.0	37.42	.10	Aug. 29	+17.8	5 g	-3.8	.851	0.5
9225	2.8	57.50	.06	July 17	+26.7	6 g	-3.0	.877	1
9374	54.3	34.52	.05	July 17	+26.7	4 p	-3.0	.890	0.5
9707	170.1	35.69	.06	July 25	+18.2	6 g	-4.1	.894	1
11103	349.0	39.22	.09	Oct. 17	+ 8.9	6 g	-3.7	.889	1
Mean:					+18.5		-3.4±0.1	5.888±.004	

rection no weights were employed. The mean values of the constants used in the reduction of the *Mars* photographs are given in the last line together with their probable errors. The weighted mean temperature of the double star observations is +18.5, that of the *Mars* observations +16.5.

4. DETERMINATION OF THE DIAMETER OF MARS FROM MEASURES OF THE LIMB

The settings on the edges of the disk made on 40 plates during the second series of measures furnish the material for a determination of the apparent diameter of *Mars*. One plate (368) was rejected, because, being overexposed, it had been reduced with a solution of ferricyanide of potassium, a treatment which considerably changed the appearance of the edge of the images. On the other hand, a later plate (459), taken when *Mars* was more distant, could be used for the diameter, although not suitable for measuring markings. On this plate only the cusp diameters were measured which, however, are nearly parallel to the polar axis. There were thus 147 images available for each of which the polar and equatorial diameters had been measured in four positions of the plate; 103 of these had been taken with the yellow filter, 44 with the red one; there should further be added the four images of plate 459, mentioned above.

The yellow images have a rather sharp edge at the limb, and to this the micrometer wires were made tangent. The red images show a more gradual fading toward the limb, but still there was some appearance of an edge at which the micrometer settings could be made. Great difficulty was encountered at the terminator where the transition from illumination to darkness is very gradual; in this case the settings had to be made to the extreme limit at which any exposure of the film was noticeable, and they are necessarily more uncertain.

The measured diameters were first corrected for the thickness of the micrometer wire (0".118) and for refraction and expressed as corrections (O-C) to the values

of the *American Ephemeris*. Table 2 presents the results of the diameter measures, giving in the first column the number of the plate, in the second the mean date of the four exposures in Greenwich Mean Time, in the third the mean quality of the images estimated on the following scale: 1.2 for excellent, 1.0 for good, 0.7 for fair, 0.3 for poor; in the fourth column the diameter of *Mars* according to the *American Ephemeris*. The equatorial and polar diameters of the illuminated part of the disk are obtained by subtracting the phase corrections q_E and q_P of col. 5 and 6 from the Ephemeris diameter. The calculation of the phase corrections needs some explanation.

Phase Correction.—As the terminator is an ellipse, while the limb is a circle, the two points T and T' (see Fig. 1) at which the micrometer wire is tangent to the

Figure 1.

illuminated disk do not lie on the same diameter. In this figure, x represents the phase correction to be calculated; it can be expressed as a function of φ (greatest defect of illumination) and α (angle between micrometer wires and cusp diameter). Using the

TABLE 2
MEASURES OF THE DIAMETER OF MARS

Plate	Date of expos. G.M.T.	Qual. of im.	Ephe. diam. <i>d</i>	Phase Correction		Yellow Filter O-C			Red Filter O-C			Flattening		Yellow-red diam.	Wt.	Plate mean O-C	Wt.	Diam. at unit dist.	Corr. to pos. A. of pol. Axis	Wt.
				<i>q_E</i>	<i>q_P</i>	Equ.	Pole	No.	Equ.	Pole	No.	Yellow	Red							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	1924											%	%	%						
333	Aug. 20. 910	1.0	25.09	.02	.04	+.14	-.14	4				+1.1				+.12	1.0	9.40	-4.5	2.9
339	21. 840	.7	25.10	.01	.04	+.42	+.31	2				+.4				+.49	.35	.54	-1.8	1.3
340	21. 869	.6	25.10	.01	.04	+.15	-.17	2				+1.3				+.11	.3	.40	-.4	1.3
344	22. 754	.6	25.11	.00	.05	+.28	-.10	1	-.07	-.42	1	+1.5	+1.4	+1.3	.8	+.16	.3	.42	-.9	1.8
345	22. 811	1.0	25.11	.00	.05	+.07	-.22	3	-.40	-.57	1	+1.2	+.7	+1.6	1.2	.00	1.0	.36	-.6	4.2
346	23. 798	.6	25.10	.00	.05	+.15	-.06	4				+.8				+.17	.6	.42	+.7	3.3
348	23. 928	.9	25.09	.00	.05	+.07	-.16	4				+.9				+.08	.9	.39	+.6	3.3
350	24. 764	.6	25.08	.00	.05	+.15	-.24	4				+1.6				+.08	.6	.39	+1.3	3.8
351	24. 854	1.1	25.08	.00	.05	+.15	-.15	4				+1.2				+.12	1.1	.41	+0.9	4.3
355	25. 812	.7	25.05	.00	.05	-.15	-.49	4				+1.4				-.20	.7	.29	+1.1	4.5
358	26. 790	1.0	25.02	.01	.05	+.12	-.24	4				+1.4				+.06	1.0	.38	0.0	4.5
361	28. 769	1.0	24.92	.03	.06	+.14	-.15	2	-.02	-.38	2	+1.2	+1.5	+.8	1.5	+.13	1.0	.41	-0.5	4.5
362	28. 851	1.0	24.91	.03	.06	+.10	-.07	2	+.05	-.34	2	+.6	+1.6	+.6	1.5	+.17	1.0	.42	+.2	3.7
363	29. 812	1.2	24.85	.05	.06	+.02	-.18	3	-.05	-.31	1	+.8	+1.0	+.4	1.2	+.08	1.2	.39	+1.5	4.6
368	30. 792	1.0	24.78	.06	.07			4											-1.2	4.0
371	31. 790	1.0	24.70	.08	.07				-.13	-.24	4		+.4			+.16	1.0	.42	-2.2	4.6
372	31. 837	.6	24.70	.08	.07	+.15	+.01	4				+.6				+.21	.6	.44	-.8	4.9
377	Sept. 1. 825	.9	24.61	.11	.07	+.27	-.07	4				+1.4				+.23	.9	.45	-1.3	5.0
378	2. 820	1.2	24.51	.13	.07	+.07	-.03	2	+.01	-.14	2	+.4	+.7	+.3	1.5	+.21	1.2	.44	-.2	4.2
384	4. 798	1.0	24.29	.19	.07	+.06	-.04	2	+.15	-.08	2	+.4	+1.0	-.1	1.5	+.26	1.0	.46	-.6	4.2
385	4. 874	.7	24.29	.19	.07	-.31	-.36	1	-.43	-.59	3	+.2	+.7	+.7	1.1	-.17	.7	.29	-.9	2.6
386	7. 768	1.1	23.91	.28	.08	+.16	.00	4				+.7				+.23	.8	.45	-1.2	3.8
387	7. 793	1.2	23.91	.28	.08				-.16	-.38	4		+.9			+.07	.9	.39	-1.7	3.3
392	8. 805	.9	23.77	.31	.09	+.04	+.07	1	+.05	-.11	3	-.1	+.7	+.5	.8	+.30	.7	.48	-2.1	3.1
400	11. 723	1.1	23.33	.44	.08	+.36	+.15	1	+.27	-.02	3	+.9	+1.2	+.6	.8	+.44	.8	.53	-.8	4.9
401	11. 824	1.0	23.31	.44	.08	+.15	-.15	2	-.02	-.25	2	+1.3	+1.0	+.5	1.0	+.16	.8	.43	-1.4	4.3
402	13. 808	1.1	22.98	.52	.08	-.11	-.20	2	-.30	-.38	2	+.4	+.3	+.8	1.0	+.01	.8	.37	-2.8	4.5
404	15. 742	1.0	22.65	.59	.08	+.08	+.03	3	-.24	-.25	1	+.2	0.0	+1.3	.7	+.20	.8	.44	-5.5	2.6
409	21. 763	1.0	21.54	.84	.08	+.11	-.09	2	-.32	-.47	2	+.9	+.7	+1.8	.9	+.05	.8	.38	-1.8	2.8
410	21. 853	.9	21.52	.84	.08	+.03	.00	2	-.38	-.41	2	+.1	+.1	+1.9	.9	+.08	.7	.39	-1.8	2.0
412	22. 675	.5	21.36	.88	.08	+.06	+.02	3	-.21	-.12	1	+.2	-.4	+.9	.6	+.21	.4	.45	-1.8	2.0
413	22. 771	.5	21.35	.88	.08	+.46	+.22	2	+.32	+.07	2	+1.1	+1.2	+.7	.9	+.50	.4	.58	-1.5	2.1
425	26. 706	1.0	20.58	1.01	.08	-.26	-.13	2	-.44	-.37	2	-.6	-.3	+1.2	.5	+.05	.5	.38	-3.2	1.7
427	26. 830	.8	20.55	1.03	.08	+.14	+.26	4				-.6				+.47	.4	.57	-4.3	1.9
428	29. 701	.8	19.98	1.11	.07	-.32	-.20	2	-.58	-.47	2	-.7	-.6	+1.3	.5	-.05	.4	.34	-1.0	2.2
438	Oct. 8. 705	.5	18.23	1.34	.07	+.07	-.03	1				+.5				+.15	.1	.44	-1.8	0.3
439	8. 732	.8	18.22	1.34	.07	+.08	-.09	4				+.9				+.09	.4	.41	-2.6	1.2
440	11. 716	1.0	17.66	1.39	.07	-.17	-.20	4				+.2				-.03	.5	.34	-5.0	1.6
441	12. 647	.8	17.49	1.42	.07	+.08	-.05	4				+.7				+.12	.4	.43	-2.1	1.6
443	12. 763	1.0	17.46	1.42	.07	-.15	-.15	4				+.1				+.02	.5	.37	-1.3	1.5
459	22. 659	.6	15.72	1.51	.07		+.05	4								+.20	.3	.48		

radius of the planet as unit and letting $OT' = r$, we find from the triangle $OT'A$:

$$(1) \quad x = 1 - r \cos(\gamma - \alpha) \\ = 1 - r \cos \gamma \cos \alpha - r \sin \gamma \sin \alpha;$$

from the triangles ODT' and ODB :

$$(2) \quad r \cos \gamma = (1 - \varphi) \cos \beta, \quad r \sin \gamma = \sin \beta;$$

and from the triangles CBD and $CT'D$:

$$(3) \quad (1 - \varphi) \tan \beta = \tan \alpha.$$

r and γ can be eliminated from (1) by means of equations (2):

$$x = 1 - (1 - \varphi) \cos \beta \cos \alpha - \sin \beta \sin \alpha$$

Further, eliminating β by (3) and developing according to powers of φ , we have:

$$(4) \quad x = \varphi \cos^2 \alpha - \frac{\varphi^2}{8} \sin^2 2\alpha - \frac{\varphi^3}{8} \sin^2 2\alpha \cos^2 \alpha \dots\dots\dots,$$

a formula which seems better adapted to the use of

Fig. 1. $\lambda_0 = 150^\circ$, Aug. 21, *y*. Fig. 2. $\lambda_0 = 184^\circ$, Sept. 26, *y*. Fig. 3. $\lambda_0 = 184^\circ$, Aug. 20, *y*. Fig. 4. $\lambda_0 = 207^\circ$, Sept. 21, *r*. Fig. 5. $\lambda_0 = 238^\circ$, Sept. 21, *r*. Fig. 6. $\lambda_0 = 252^\circ$, Sept. 15, *r*. Fig. 7. $\lambda_0 = 283^\circ$, Sept. 11, *r*. Fig. 8. $\lambda_0 = 294^\circ$, Sept. 13, *y*. Fig. 9. $\lambda_0 = 318^\circ$, Sept. 11, *r*. Fig. 10. $\lambda_0 = 335^\circ$, Sept. 7, *y*. Fig. 11. $\lambda_0 = 335^\circ$, Sept. 7, *y*. Fig. 12. $\lambda_0 = 343^\circ$, Sept. 7, *r*.

the Ephemeris data than Bessel's treatment of the problem. In the notation of the *American Ephemeris*:

$$\varphi = 2(1-k) = \frac{2q}{\text{diameter}}.$$

For polar diameter: $\alpha = P - Q$

For equatorial diameter: $\alpha = 90^\circ + P - Q$.

Near opposition it is sufficient to use the first term of formula (4), for a few of the later plates with large phase it was necessary to include the second term. The third term never amounts to more than 0.002 and can nearly always be neglected.

Correction for image intensity.—Because of differences in exposure time, variations in the transparency of the air and in the sensitivity of the plates the images of *Mars* are not all of the same intensity, and it must be expected that the results of the individual diameter measures (not given in Table 2) depend somewhat on this factor. To investigate this question the observations were divided into three periods and for each period the yellow and red images, as well as the equatorial and polar diameters, were treated separately. In every subgroup the diameter residuals were then arranged according to the intensity of the image measured in the microphotometer and represented by a linear formula

$$O - C = a + b(J - J_0),$$

where J is the intensity of the image approximately expressed in magnitudes and J_0 an arbitrary constant close to its mean value. The coefficients b determined by least squares solutions for each subgroup are given in Table 3 together with their weight and the number of images (in brackets). In the last period the equatorial diameters were not used on account of the large phase.

TABLE 3

DEPENDENCE OF RESIDUALS ON IMAGE INTENSITY

Period							
Aug. 20-Sept. 4	Equat. diam.	$b = +.03$	Wt. 3.9	(56)	$b = +.04$	Wt. 1.5	(18)
	Polar diam.	$+.08$			$-.10$		
Sept. 7-Sept. 22	Equat. diam.	$.00$	.9	(22)	$+.20$	1.1	(22)
	Polar diam.	$-.13$			$-.04$		
Sept. 26-Oct. 22	Polar diam.	$+.10$	10.4	(29)	$+.16$	1.1	(4)
	Mean:	$b = +.068$			$b = +.048$		
			Wt. 20.0			Wt. 6.3	

The small weights of the solutions in some of the groups are mostly due to small variations in the intensity of the images. Although the dependence is not very pronounced, both yellow and red images show independently that as a whole the diameters are measured slightly larger on the stronger images. All images were then reduced to equal intensity by the small correction:

$$-.062 \cdot (J - 4.75)$$

which only in two cases reaches 0'.1. The means of the corrected residuals taken for each plate are found in Table 2, col. 7-8 for the yellow images, and col. 10-11 for the red images, with the number of images on which each mean is based in col. 9 and 12. The fact, that in our case a threefold overexposure produces an error of only '.06 in the diameter measures, illustrates clearly the advantages of the photographic method for measuring planetary diameters.

Flattening of Mars and phase effect.—We designate as true flattening F that seen at a great distance by an observer situated in the plane of the planet's equator and measure it, as usual, by the fraction

$$F = \frac{\text{equat. diam.} - \text{polar diam.}}{\text{equatorial diameter}}.$$

The apparent flattening f seen from the Earth is related to it by the series of formula (4) of which we need to retain only the first term:

$$f = F \cos^2 D$$

where D is the areocentric declination of the Earth referred to the Martian equator as given in the *American Ephemeris*. On the other hand, the apparent flattening is derived from the measured polar and equatorial diameters d_p and d_e by

$$f = \frac{d_e - d_p}{d_e} \text{ or } f = \frac{R_e - R_p}{d}$$

if R_e and R_p represent the residuals of Table 2, col. 7-8 and 10-11 and d the Ephemeris diameter of col. 4. The results for f obtained by this formula are found in col. 13 and 14 of Table 2. Taking means for the three observing periods, as in col. 4, 5, 6 of Table 4, it becomes evident that the observed flattening decreases with increasing phase defect; for the sake of comparison col. 2 and 3 of Table 4 give the mean phase cor-

rections for each period expressed in fractions of the radius: φ_e in the direction of the equator and φ_p in the direction of the pole. The gradual fading at the terminator must have introduced a systematic error in the micrometer settings. It seems most likely that this error is proportional to the phase defect and the observed values of the flattening f' are then represented by the formula:

$$f' = F \cos^2 D - \sigma(\varphi_e - \varphi_p).$$

TABLE 4
EFFECT OF PHASE ON OBSERVED FLATTENING

Period		Mean phase cor.		Observed flattening f'		Mean	Formula
		φ_E	φ_P	Yellow im.	Red images		
Aug. 20-Sept. 4	4	.002	.002	+ .0103 (56)	+ .0091 (18)	+ .0100 (74)	+ .0096
Sept. 7-Sept. 22	22	.026	.004	+ .0056 (22)	+ .0070 (22)	+ .0063 (44)	+ .0066
Sept. 26-Oct. 22	22	.067	.004	+ .0013 (25)	- .0045 (4)	+ .0004 (29)	+ .0009

The true flattening F and the coefficient of the additional phase correction σ were determined by a least squares solution from the mean f' of each plate (combining the data of the red and yellow images) and using weights proportional to the square of the apparent diameter. The results of this solution are:

$$F = +.0104 \pm .0006$$

$$\sigma = +.134 \pm .021$$

On the photographic images the phase defect appears about 13% too large, and the micrometer settings must have been made 0".1 or more inside of the terminator in the later observations although they were made to the extreme edge visible. On photographs with exposures suited for studying the markings the true terminator does not seem to be visible at all, but the images stop short at a region where the Sun is still 1.5 above the horizon. It is interesting to note that this situation is opposite to that prevailing in visual observations. Lowell³ finds that visual micrometer measures on the terminator give too small a phase; they must include the so-called twilight arc.

The polar flattening of *Mars* seems well determined, having a probable error of only 6%. After applying the additional phase corrections the flattening can be derived separately for the yellow and red images:

$$\text{Yellow images } F = +.0106 \pm .0007$$

$$\text{Red images } F = +.0098 \pm .0011$$

The agreement is very good, but the discussion of this result will be taken up later.

Difference in diameter of yellow and red images.—For all plates on which exposures with both color filters had been made the differences between the diameter measures of the yellow and the red images were formed. Taking means for the equatorial and polar diameters for each plate these differences are given in percentages of the diameter in col. 15 of Table 2. Out of the 19 figures 18 are positive, demonstrating in an impressive way that yellow photographs of *Mars* appear larger in diameter than red ones. The weights (col. 16) of the individual results depend, of course, on the numbers n_1 and n_2 of the two kinds of images according to the formula $\frac{n_1 n_2}{n_1 + n_2}$; they are further proportional to the square of the apparent diameter, and finally the equa-

torial diameters were given half weight in the second period and were not used at all in the last period on account of the uncertainty introduced by the phase. The weighted mean of the systematic difference between yellow and red images is

$$\text{Yellow} - \text{red} = 0.82\% \pm 0.08\%$$

This result is based only on a part of the plates and another determination was made (Table 5) by calculating the mean residuals of the yellow and red images for each observing period (2d and 3d col.) after correcting the individual data for phase error and flattening. The differences between the mean residuals divided by the mean diameter (col. 4) furnish the results of the 5th column.

TABLE 5
SYSTEMATIC DIFFERENCE OF YELLOW AND RED IMAGES

Period	Mean residuals		Mean diam.	Yellow-red diam.	Wt.
	Yellow im.	Red im.			
Aug. 20-Sept. 4	+0".11 (56)	-0".09 (18)	24".7	+0.81%	13
Sept. 7-Sept. 22	+0.22 (22)	0.00 (22)	22.7	+0.97	7
Sept. 26-Oct. 22	+0.13 (29)	-0.21 (4)	20.3	+1.68	1
Mean.....	.....	.....	.....	+0.90%	

While the first method is free from small systematic errors peculiar to each plate, the second utilizes the available material more completely. Since both methods agree closely, their mean, 0.86%, has been adopted. *Mars* photographs taken with the red filter then have an apparent diameter 0.86% smaller than those taken with the yellow filter, and our observations confirm Wright's discovery of such an effect. Wright⁴ finds a difference of 3% in diameter between the violet ($\lambda = 4400$ A.) and infra-red ($\lambda = 7600$ A.) images. In our case the mean wavelengths of the two colors differ much less, being about 5600 A. for the yellow and 6000 A. for the red. Relating the diameter difference to the wave-length difference we have:

	Wave-length interv.	Diff. of diam.	Change per 1000 A.
Wright.....	4400-7600 A.	3%	0.9%
Trumpler.....	5600-6000	0.86%	2.1%

³ *Ann. Lowell Obs.* 1, 59.

⁴ *L. O. Bull.* 12, 53, 1925.

The drop in the apparent diameter evidently is not uniform for the whole color range. Wright's measures, combined with our results, indicate that between the ultraviolet, violet and yellow the *Mars* images undergo little alteration in diameter. Between the yellow and red or infra-red a rapid shrinking of the image takes place, which seems to mark the transition from the disk of *Mars* seen with its surrounding atmosphere (or at least a part of it) to the disk representing the solid surface alone. The evidence supporting the view that the infra-red photographs present the size of the solid surface will be given later (page 33).

Results for the diameter of Mars.—We proceed now to make all our diameter measures homogeneous, reducing them to the system of equatorial diameters of yellow images by the following corrections:

Additional phase correction:	Equat. diam.	+0.134 q_z
	Polar diam.	+0.134 q_p
Correction for app. flattening:	Polar diam.	+0.0104 $d \cos^2 D$
Correction for color:	Red images	+0.0086 d

Column 17 of Table 2 contains the plate means of the corrected residuals. As the micrometer settings on the terminator increase in uncertainty with the phase the equatorial diameters received full weight for the first period (Aug. 20–Sept. 4), half weight for the second period (Sept. 7–Sept. 22), and were rejected in the last period, where they serve only the purpose of studying the phase effect. The weights (col. 18) of these plate means are the product of the number of observations used and the quality of the images (col. 3). Unit weight is thus attributed to the result of a plate of “good” quality on which both equatorial and polar diameters of four images had been measured in four positions of the plate. Col. 19 gives the diameters at unit distance corresponding to the residuals of col. 17.

The correction a to the Ephemeris value (9".36) of the diameter of *Mars* at unit distance was first determined from the residuals of col. 17 by a least squares solution with equations of condition of the form

$$\frac{a}{\Delta} = O - C \quad (\Delta = \text{distance of } Mars \text{ in astr. units})$$

with the result $a = +0".053$, or,

$$\text{Equatorial diameter of } Mars: 9".413 \pm ".009$$

(First solution).

It has, however, been a general experience that metric measures of planetary diameters, especially those made visually, are affected by considerable systematic errors, mostly due to irradiation and diffraction as well as to a personal equation in the conception of the edge. The effect of such errors is essentially independent of the size of the disk or the distance of *Mars* and can be determined together with the diameter, if the measured

disks vary sufficiently in size (Method of Hartwig and Campbell). A second solution was accordingly made by introducing a constant term b into the equations of condition

$$\frac{a}{\Delta} + b = O - C$$

with the result $a = +0".01 \pm ".06$ and $b = +0".10 \pm ".16$, or,

$$\text{Equatorial diameter of } Mars: 9".37 \pm ".06$$

(Second solution).

Both solutions represent the observations about equally well, leading to a probable error of $\pm ".078$ for unit weight.

In the second solution, unfortunately, the two unknowns are not well separated and the probable error of the result is therefore large. All we can learn from it is, that the systematic measuring error is small, of the order of 0".1, in the sense that the images were measured too large. Another means for estimating the possible size of some of these systematic errors is furnished by the comparison of strong and weak exposures. When correcting our measures for differences in the intensity of the photographic images a median intensity ($J=4.75$) was somewhat arbitrarily chosen as standard. If a greater or smaller intensity had been selected as standard all the corrected diameter measures would have been increased or decreased by the same amount, but in no case could this systematic difference have exceeded 0".1. The constant b would have been zero for the weakest measurable images. It is improbable, therefore that our measures are affected by a systematic error of more than 0".1, which enters into the final result only by one-third of its amount, and it seems justifiable to adopt the first solution leading to the following results:

Yellow images:	Equatorial diameter	9".41
	Polar diameter	9.32
Red images:	Equatorial diameter	9.33
	Polar diameter	9.24
Polar flattening of <i>Mars</i>	$0.0104 \pm .0006 = 1/96$	

Red images are 0.86 percent smaller than yellow images.

The polar diameter is that seen by an observer situated in the plane of the equator of *Mars* at a distance of 1 astronomical unit. The probable error of the diameter results is about $\pm ".02$ including accidental and systematic sources of error.

The polar diameter of the yellow images should be quite comparable with the results of visual observers and agrees indeed very closely with the best of these:

Hartwig ⁵ (Heliometer)	9".352
Campbell ⁶ (Micrometer)	9.25

⁵ *Publ. d. Astron. Ges.* 15, 77, 1879.

⁶ *Astron. Jour.* 15, 145, 1895.

5. DIAMETER, FLATTENING AND POSITION OF POLAR AXIS FROM MEASURES OF SURFACE MARKINGS

The measures of the markings made on 151 photographic images of 40 plates were described on page 22. Each plate furnishes a list of rectangular coordinates referred to the center of the disk, oriented to the pole and equator of *Mars* according to the data of the *American Ephemeris* and expressed in fractions of the equatorial radius of the planet (with the approximate diameter value of 9".248).

On page 21 a method was outlined in its main ideas by which it is possible to derive the diameter of the solid surface from such measures, as well as the position of the axis of rotation. Instead of establishing the apparent elliptical path of a marking across the disk directly from the observations, it is more convenient to calculate this path with approximate values of the areographic position of the marking and of the planetary constants, to compare the calculated rectangular coordinates with the observed ones and to determine from the resulting residuals differential corrections for the desired quantities. For this purpose we have to set up the formulae by which the rectangular coordinates are related to the areographic longitude λ and latitude β . This is easily done if we assume first that the surface of the planet is a perfect sphere and define the position of any point on it by three auxiliary rectangular coordinates ξ, η, ζ (fig. 2); the ξ axis being

Figure 2.

perpendicular to the plane of the central meridian, the η axis falling into the polar axis of the planet (positive toward the North pole), the ζ axis in the intersection of the central meridian with the equator. We choose the equatorial radius of *Mars* as unit and designate with λ_0 the longitude of the central meridian; ξ, η, ζ are then found by the equations:

$$\begin{aligned} \xi &= \cos \beta \sin(\lambda - \lambda_0) \\ \eta &= \sin \beta \\ \zeta &= \cos \beta \cos(\lambda - \lambda_0) \end{aligned} \quad (5)$$

From these auxiliary coordinates the measured ones x, y are obtained by simply rotating our coordinate system around the ξ axis by the angle D which is the declination of the Earth referred to the center and equator of *Mars* and is given by the *American Ephemeris*. The transformation of coordinates representing such a rotation is:

$$\begin{aligned} x &= \xi \\ y &= \eta \cos D - \zeta \sin D \end{aligned}$$

and eliminating ξ, η, ζ by means of (5) we have

$$\begin{aligned} x &= \cos \beta \sin(\lambda - \lambda_0) \\ y &= \sin \beta \cos D - \cos \beta \sin D \cos(\lambda - \lambda_0) \end{aligned} \quad (6)$$

If, however, *Mars* is assumed to be an ellipsoid of rotation, flattened at the poles by an amount F as defined on page 25, these equations have to be slightly altered. Fig. 3 presents a cut through the meridian of the point P in consideration. Besides the surface of the planet the concentric sphere tangent at the equator is also drawn. Projecting the point P of the ellipsoid to the sphere at P' by a line parallel to the polar axis, we designate with β' the latitude of the projected point and find for the coordinates η and ρ of P (remembering that $OP' = 1$)

$$\begin{aligned} \rho &= \cos \beta' \\ \eta &= (1 - F) \sin \beta' \end{aligned}$$

Figure 3.

It is evident then, that by replacing in (5) and (6) $\cos \beta$ by $\cos \beta'$ and $\sin \beta$ by $(1 - F) \sin \beta'$ we obtain the corresponding formulae for the flattened ellipsoid:

$$\begin{aligned} x &= \cos \beta' \sin(\lambda - \lambda_0) \\ y &= (1 - F) \sin \beta' \cos D - \cos \beta' \sin D \cos(\lambda - \lambda_0) \end{aligned} \quad (6')$$

But the true planetocentric latitude is β and not β' .

The relation between these two quantities is derived from the triangles $OP'P''$ and OPP'' (fig. 3):

$$\frac{tg\beta}{tg\beta'} = \frac{PP''}{P'P''} = 1 - F$$

$$tg\beta = (1 - F)tg\beta'$$

According to Lagrange this can be developed into a power series for the small quantity F :

$$(7) \quad \beta = \beta' - \frac{F \sin 2\beta'}{2 \sin 1^\circ} + \dots$$

where β and β' are expressed in degrees. Higher order terms may be neglected, as for a flattening of $F=0.01$, $\beta - \beta'$ amounts at the extreme to 0.3 . It is convenient first to determine β' for each marking and to apply the small corrections (7) only in the final catalogue.

For a selected marking the equations (6') represent its apparent path across the disk as a function of the variable parameter λ_0 . Since the period of rotation of *Mars* is very accurately known, λ_0 , the longitude of the central meridian, can be interpolated from the *American Ephemeris* for the time of each exposure on which our marking was measured, and we may assume these data to be free from error, even when the exposures are taken on different days. With approximate values of F and D and of the longitude and latitude of our marking its rectangular coordinates for the date of each plate are calculated by (6'). The differences between these calculated coordinates x_e, y_e and the observed ones x_0, y_0 must then be due to the following causes, aside from the accidental measuring errors:

- (a) Errors in the assumed values of λ and β'
- (b) Errors in the constants F and D
- (c) Errors in the orientation of the plate and in the scale of the x_0, y_0 ; the latter are introduced by expressing the coordinates as fractions of an incorrect value of the planet's radius.

The six errors mentioned, or the corresponding corrections, can be determined from the residuals by a least squares solution for which we have now to derive the equations of condition. The first four corrections affect the calculated coordinates, and we have to differentiate the equations (6'):

$$dx_e = \cos \beta' \cos (\lambda - \lambda_0) d\lambda - \sin \beta' \sin (\lambda - \lambda_0) d\beta'$$

$$dy_e = \cos \beta' \sin D \sin (\lambda - \lambda_0) d\lambda + \{ \cos \beta' \cos D + \sin \beta' \sin D \cos (\lambda - \lambda_0) \} d\beta' - \sin \beta' \cos D dF - \{ \sin \beta' \sin D + \cos \beta' \cos D \cos (\lambda - \lambda_0) \} dD,$$

Since F is a small quantity, terms containing the products $F d\beta'$ and $F dD$ can be neglected. The corrections of the observed coordinates for orientation and scale are:

$$dx_0 = -x_e dR - y_e dP$$

$$dy_0 = -y_e dR + x_e dP$$

where dR is the fraction of the radius by which its assumed value should be increased, while dP is the correction in arc measure to the position angle of the polar axis as given in the *Ephemeris*. Since

$$x_0 + dx_0 = x_e + dx_e$$

$$y_0 + dy_0 = y_e + dy_e$$

our equations of condition take the form:

$$(8) \quad \begin{aligned} x_0 - x_e &= x_e dR + y_e dP + \cos \beta' \cos (\lambda - \lambda_0) d\lambda \\ &\quad - \sin \beta' \sin (\lambda - \lambda_0) d\beta' \\ y_0 - y_e &= y_e dR - x_e dP + \cos \beta' \sin D \sin (\lambda - \lambda_0) d\lambda \\ &\quad + \{ \cos \beta' \cos D + \sin \beta' \sin D \cos (\lambda - \lambda_0) \} d\beta' \\ &\quad - \sin \beta' \cos D dF - \{ \sin \beta' \sin D \\ &\quad + \cos \beta' \cos D \cos (\lambda - \lambda_0) \} dD \end{aligned}$$

As long as the n measures of a single point are considered, they furnish $2n$ such equations for the determination of 6 unknowns; but in no case can all these be obtained with satisfactory weight from one point alone. Let us take for example a point at the equator of *Mars* ($\beta' = 0$) and assume that three observations of it are available, made at such times that $\lambda - \lambda_0$ has the values $-60^\circ, 0^\circ, +60^\circ$. Although we have six equations with six unknowns, dF remains indeterminate, because its coefficients in the equations are all zero; for $dR, dP, d\lambda$ the solution is quite satisfactory, while $d\beta'$ and dD have small weight on account of not being well separated. On the other hand the measures of a marking near the pole furnish $\cos \beta' d\lambda, d\beta', dP$ and the difference $dR - dF$ with good accuracy, but they contribute little toward the determination of dR and dD . It is clear then that the flattening dF must be found by combining equatorial points with others near the pole, and a satisfactory accuracy for dD has to rest on a large number of observations. For all markings it is important that the observations cover a wide range of areocentric hour angles. Since most configurations appear somewhat distorted when seen near the limb, great care has to be exercised in the correct identification of the selected points, and it is desirable to use numerous markings of different character in order to eliminate as far as possible systematic errors due to this source.

Our measures seem to satisfy these conditions and 192 points between latitudes -79° and $+50^\circ$ were selected for the solution with a total of 1409 observations (one observation designates the mean result of the different images, generally four, of the same plate). Only points with too few or poorly distributed measures were omitted. The problem before us is to determine λ and β' for 192 points as well as the four constants dR, dP, dD, dF , a total of 388 unknowns, from 2818 equations of condition. Several simplifications, however, seem possible without much loss in accuracy.

In the first place the determination of dP was separated from the other unknowns. It has been mentioned before that the zero point of position angle was taken over from the double star observations of the following year, and it seemed desirable to determine dP for each plate so as to test the constancy of the zero point by the agreement of the different plates. Only the y measures of two groups of 6–10 equatorial points were used for this purpose, one group being situated near the eastern limb, the other near the western limb. The second equation of (8) shows that for such points the coefficient of dP is large and has opposite sign for the two groups. The preliminary catalogue (mentioned on page 21) furnished approximate areographic positions for the points needed for the calculation of y_c . Subtracting the mean residual $y_0 - y_c$ of the western group from the corresponding mean residual of the eastern group and dividing by the mean x difference of the two groups dP is obtained, neglecting the other differential corrections. Although this method is not quite rigorous, it can be shown that the omissions are of little consequence and the results for dP , expressed in degrees, are given with their weights in the last two columns of Table 2. The weighted mean is

$$dP = -1.0 \pm .2.$$

The probable error also takes account of the uncertainty in the zero point.

Correcting the residuals for this value of dP we eliminate one unknown from our equations of condition. With close approximations for the λ 's obtained from our preliminary catalogue the terms with $\cos \beta' d\lambda$ can be neglected in the determination of the three constants dR , dD , dF . Not only are the products $\cos \beta' d\lambda$ small, but they have the character of accidental errors and are independent of the other unknowns whenever the observations of a point are symmetrically arranged with respect to the central meridian, a condition which is well fulfilled for most of our points. The equations of condition (8) can now be simplified by leaving out the terms with dP and $d\lambda$ and we can further replace on the right hand side x_0 and y_0 by x_c and y_c or by their expressions in λ and β' according to (6').

$$\begin{aligned} x_0 - x_c &= -\sin \beta' \sin(\lambda - \lambda_0) d\beta' + \cos \beta' \sin(\lambda - \lambda_0) dR \\ (9) \quad y_0 - y_c &= \{ \cos \beta' \cos D + \sin \beta' \sin D \cos(\lambda - \lambda_0) \} d\beta' \\ &\quad - \cos \beta' \sin D \cos(\lambda - \lambda_0) dR - \{ \sin \beta' \sin D \\ &\quad + \cos \beta' \cos D \cos(\lambda - \lambda_0) \} dD - \sin \beta' \cos D d\Phi \end{aligned}$$

where dF was replaced by the new unknown

$$d\Phi = dF - dR.$$

While it would be possible to set up the 195 normal equations of which all but three contain only four unknowns, much computing work can be saved by the

following consideration. The solution would be very simple if we could neglect the $d\beta$'s in a similar way as the $d\lambda$'s. Unfortunately this is not possible because the $d\beta$'s are closely related to the constants dD and $d\Phi$. They are not like accidental errors but rather like systematic errors showing a certain run with β' and this run depends on the corrections dD and $d\Phi$. In view of the symmetrical arrangement of our observations, the $d\beta$'s will, however, be purely accidental for all points which have the same latitude, and for our solution it is sufficient to retain the mean systematic corrections as a function of the latitude, neglecting the individual corrections of each point. Our 192 points were accordingly divided into 16 latitude intervals in general 10° wide, except near the South pole where they are narrower. For all points of the same latitude interval the correction $d\beta'$ was assumed to be the same. There were thus 19 normal equations to be set up from the 2818 observations. The calculation of the coefficients was greatly facilitated by the fact, that for the different observations of the same point only $\lambda - \lambda_0$ varies, and further by substituting the mean β' of the latitude interval for the individual values of each point and the constant mean value -16.25 for D , which varies little during the period of observation. The weight of each observation was adopted proportional to the number of images on which it rests (weight 1 for 4 images). As the different corrections $d\beta'$ are independent of each other, the solution of the normal equations is relatively simple and led to the following results:

$$\begin{aligned} dR &= -.0078 \pm .0015 & R &= 9.176 \pm .014 \\ (1st \quad dD &= +.0019 \pm .0033 & dD &= +0.11 \pm .18 \\ solution) \quad d\Phi &= +.0142 \pm .0033 & dF = d\Phi + dR &= +.0064 \pm .0036 \\ & & F &= +.0163 \pm .0036 \end{aligned}$$

The value of the flattening of *Mars* is considerably larger than that derived from the settings on the limbs. This suggests that in the latter case the polar diameter was measured too large on account of the great intensity of the polar cap on most of the photographs. But the irradiation of the polar cap will also affect the determination of the center of the disk by a similar systematic error. If this interpretation is correct, all the measured y coordinates need a constant negative correction, and a second solution was made including as additional unknown such a correction c . The only change in the equations of condition is that the term $-c$ has to be added to the second equation of (9), and the procedure of the solution was quite similar:

$$\begin{aligned} dR &= -.0076 \pm .0015 & R &= 9.178 \pm .014 \\ (2d \quad dD &= +.0058 \pm .0041 & dD &= +0.33 \pm .24 \\ solution) \quad d\Phi &= +.0090 \pm .0046 & F &= +.0113 \pm .0048 \\ & & c &= -.0070 \pm .0043 \end{aligned}$$

Our supposition concerning the effect of the irradiation of the polar cap on the determination of the

Fig. 1

Fig. 2

center of the disk is indeed confirmed by the negative value of c and the results of the second solution were adopted as final, although the introduction of a new unknown has resulted in a reduction of the weight of dD and $d\Phi$.

6. THE POLAR FLATTENING OF MARS

We have now determined the polar flattening of *Mars* by two methods entirely different in character but with results in close agreement:

From measures of equat. and polar diam.	$F = .0104 \pm .0006$
From measures of markings:	$F = .0113 \pm .0048$
Mean:	$F = .0108 = 1/93$

As our figures are contradicted by theoretical considerations, a careful discussion of the possible sources of systematic errors seems desirable. It might be thought that imperfect guiding would slightly elongate the photographic images in the direction of the daily motion which for our observations differs only about 10° from the Martian equator. This would, of course, affect the measures of the limb as well as those of the markings. This source of error, however, must be ruled out. In the first place, it is unlikely that short exposures of $1\frac{1}{2}$ seconds like those of the yellow images should be systematically affected by guiding. In the second place, such an effect should increase with the exposure time, and the red images with 18 seconds exposure should give a larger flattening, while in fact their result is even a trifle smaller (page 26).

The direct diameter measures made by settings on the limb or the terminator could be influenced by variations in the illumination of the different parts of the edge. For the terminator such an effect was indeed found, discussed and corrected for. Any effect of the phase on the determination of the flattening is completely eliminated for the period from Aug. 28 to Sept. 1, when the line connecting the cusps forms an angle of 45° with the polar axis; the phase defect of the polar diameter is then the same as that of the equatorial diameter. The six plates of this period taken separately give $F = .0103$ a result practically identical with that of the whole series.

There remains the irradiation of the polar cap which could only have operated in the sense of producing too small a flattening. On seven plates taken in September the polar cap is very faint and pale. These plates alone when corrected for phase give $F = .0101$, while for the 24 earlier plates on which the polar cap is brilliant we find $F = .0107$; the difference is again inappreciable.

Still more convincing is the comparison with the results of other observers. It is true that visual micrometric measures have yielded widely divergent data for the flattening of *Mars* ranging from 0 to .06. But if

we confine ourselves to the best and most complete series of recent times, the results are more consistent.

1. Hartwig⁷ discussed the measures of the diameter of *Mars* made with the heliometer or double image micrometer at Königsberg, Leiden, Oxford, Berlin, Paris, Strassburg, and gives for the flattening:

$$F = 1/96 = .0104 \quad \text{Wt. 2.}$$

2. From a special series of observations with the Breslau heliometer made in 1879 for the purpose of studying the flattening Hartwig⁸ finds:

$$F = 1/116 = .0086 \pm .0022 \quad \text{Wt. 1.}$$

3. Among the measures with the filar micrometer we may mention those of Young⁹ made with the $9\frac{1}{2}$ -inch refractor at Princeton in 1879:

$$F = 1/219 = .0046 \pm .0018 \quad \text{Wt. } \frac{1}{2}.$$

4. Barnard's¹⁰ measures with the micrometer of the 36-inch refractor of the Lick Observatory in 1894 give:

$$F = 1/109 = .0091 \quad \text{Wt. 1.}$$

5. Numerous micrometric measures of the equatorial and polar diameters of *Mars* were made at the Lowell Observatory in the years 1894 and 1896. Using only the observations near opposition the following values of the flattening are obtained:

1894	$F = .0061$	(Oct. meas.) ¹¹
1896	.0248	(Oct.-Nov. meas., first reduction) ¹²

$$\text{Mean} \quad F = .0154 \quad \text{Wt. 1.}$$

The small result by Young rather falls out of line, but it must be mentioned that these measures are strongly affected by irradiation and give a value of the diameter of *Mars* $1''.46$ too large; it is on this account that they were given half weight. Taking means for each method of observation with the weights indicated we have:

Heliometer	$F = .0098$
Filar micrometer	.0107
Photogr. meas. of diameter	.0104
Photogr. meas. of markings	.0113

and we may adopt their mean as the best available

$$\text{observational result for the polar flattening of Mars} \\ F = .0105 = 1/95.$$

The good agreement of four different methods leaves no doubt that the disk of *Mars* appears in the telescope

⁷ *Publ. d. Astron. Ges.* 15, 78, 1879.

⁸ *A. N.* 150, 313, 1899.

⁹ *Amer. Jour. of Science*, 3d series, 19, 206, 1880.

¹⁰ *A. J.* 17, 145.

¹¹ *Ann. Lowell Obs.* 1, 61-62.

¹² *Ann. Lowell Obs.* 2, 246.

flattened by about 1 percent and that this phenomenon is not due to purely instrumental or personal errors.

There are two theoretical considerations bearing on the polar flattening of *Mars*. In the first place, such a flattening will cause secular perturbations in the motions of the satellites. H. Struve¹³ calculated by this method the position of the polar axis and the amount of flattening, for which he obtained:

$$F = 1/190 = .0053$$

a value much smaller than the observed one. Struve's result, however, can hardly be considered as being established beyond any doubt or question. The measures of the satellites, which are very difficult, may be subject to considerable systematic errors introduced principally by the uncertainties in the center of *Mars* to which they are referred. The observations are furthermore not continuous but confined to short periods around the favorable oppositions and separated by several years. This is well illustrated by the fact that for both satellites the eccentricities derived show a wide range. The value of the flattening is principally based on the motion of the perimartium of *Phobos* and on the changes in the orbit plane of *Deimos*. While the latter have not even completed a period, the different determinations of the perimartium of *Phobos* taken alone, could equally well be represented by a shorter period (0.90 years), corresponding to a larger flattening. It should also be mentioned that the perturbations of the satellites on each other were neglected and that the position of the plane of the equator derived by this method is not in good agreement with the results of direct observation.

Clairaut's Theorem states the condition for liquid equilibrium on the surface of the planet, which is:

$$F \leq \frac{5}{4} \varphi$$

where φ , the ratio of the centrifugal force to the gravitational attraction at the equator, can be calculated from the mass, period of rotation and the equatorial radius of the solid surface. Adopting for the latter the result (4".59) of our measures of markings and for the mass of *Mars* Struve's value 1:3 090 000, we obtain;

$$\varphi = .00434 = 1/231$$

and Clairaut's Theorem would require:

$$F \leq .00542 \quad (1/185)$$

where the sign of equality applies to the case of uniform density in the interior of the planet, while greater density at the center leads to a smaller value of F .

¹³ A. N. 138, 217, 1895; *Mem. de l'Acad. Imp. des Sciences de St. Petersburg* 8^e series, 8, No. 3, 1898; *Sitzungsber. Berlin Akad.* 1911, p. 1056.

Our observational results for the flattening are incompatible with Clairaut's Theorem and there are only two assumptions, both equally improbable, which could explain such a discrepancy; either that the density of *Mars* is greater near the surface than at the center, or that the surface of *Mars* is not in liquid equilibrium. Although *Mars* does not seem to have any large water surfaces, there can be no doubt that its atmosphere must be in liquid equilibrium. It will presently be shown that the visual or photographic measures of the limb refer to a certain layer of the atmosphere and the flattening derived from them should, therefore, conform to Clairaut's Theorem.

Unless we are willing to admit an abnormal density distribution in the interior of *Mars*, the only way out of the dilemma seems at present to lie in a suggestion made by Hartwig, W. H. Pickering and others that the observed values of the flattening are influenced by peculiarities in the Martian atmosphere. This atmosphere must then be visible up to a higher level (52 miles) at the equator than at the poles (42 miles), and consequently different amounts of it are included in the measures of equatorial diameters than in those of polar diameters. Such an effect might easily be produced by the circulation in the Martian atmosphere. As the limbs of the red images refer to a lower atmospheric level, about $\frac{2}{3}$ in elevation compared with the corresponding level of the yellow images, they should give a flattening intermediate between that of the yellow images and the theoretical value (ca. .005) of the solid surface. In fact the result of the red images taken alone (page 26) is a trifle smaller, although not as much as we should expect, but the difference lies within the limits of its probable error. On the other hand our suggestion does not explain the value of the flattening derived from the measures of the markings. Considering, however, its rather large probable error, it is not impossible that the agreement with the results of the limb measures is purely accidental. This question could probably be cleared up in a more definite way by measuring the flattening on infra-red images, the limbs of which do not seem to include any of the atmosphere, and by further determinations of the flattening from measures of markings.

7. THE DIAMETER OF MARS

From the rotational movement of the markings we have obtained (2d solution, page 30) the following results for the

Diameter of the solid surface of Mars at unit distance:

Equatorial diameter $9''.178 \pm .015 = 6652 \pm 11$ km.
(4133 $\pm$ 7 miles)

Polar diameter $9''.075 \pm .047 = 6577 \pm 34$ km.
(4087 $\pm$ 21 miles)

The probable errors include the uncertainty of the scale value and for the polar diameter that of the flattening. This is the first attempt to determine the diameter of the solid surface and, as we expected, this constant is considerably smaller (ca. 2%) than the generally adopted value of the diameter of *Mars* which is based on measures of the limb. We thus confirm Wright's conclusion that the apparent disk of *Mars* as seen or photographed in ultraviolet, violet or yellow light includes part of the planet's atmosphere, and that the smaller diameters of red or infra-red photographs are due to partial or complete elimination of the scattered light of the Martian atmosphere.

It is surprising to find that Wright's diameter measures¹⁴ of the infra-red images are still smaller (8".86) than our value for the solid surface. On closer examination it is evident that Wright's measures are systematically smaller than ours even for yellow images taken with the same filter. A correction of +0".5 applied to Wright's measures will bring his result for the yellow images (9".17) into agreement with ours for the same color (9".36 mean of polar and equat. diameter). If the measures of infra-red images are similarly corrected, their mean result is 9".06 and comes close to the corresponding value 9".13 which we find to be valid for the solid surface. It appears then that the infra-red photographs represent approximately the disk of the solid surface, although for short exposures the gradual fading of light at the limb may even cause the measures to give slightly smaller results.

Comparing now the diameter of the solid surface with our measures of the limb we obtain some information on the height of the Martian atmosphere at the equator as far as it is visible on the photographs of the two colors.

Height of visible atmosphere at equator:

Yellow images 84 km. = 52 miles
Red images 55 km. = 34 miles

Even the figure of the yellow images is rather a lower limit for the extent of the atmosphere, and its highest parts are probably too tenuous to be visible at the limb by scattered light. In the twilight arc our own atmosphere becomes visible by scattered sunlight up to a height of 68 km. (42 miles).¹⁵ We have then here a direct proof that the Martian atmosphere is quite extensive; unless its scattering properties are larger, we should conclude that it reaches a height similar to that of the Earth's atmosphere. On account of the smaller gravitational attraction its density and pressure at the surface must nevertheless be much lower.

¹⁴ *L. O. Bull.* **12**, 54, 1925.

¹⁵ R. Wolf, *Handbuch der Astronomie* **1**, 475.

8. POSITION OF THE AXIS OF ROTATION

With respect to the position of the polar axis of *Mars* we found (page 30) the following corrections to the data of the *American Ephemeris*:

$$dP = -1^{\circ}0 \pm ^{\circ}2 \quad dD = +^{\circ}33 \pm ^{\circ}2$$

The first refers to the position angle, the second to the inclination with the line of sight. Applying these corrections we find for the equinox and equator of 1925.0:

Position of the North pole of Mars:

$$R.A. = 315^{\circ}9 \pm ^{\circ}3 \quad Decl. = +54^{\circ}7 \pm ^{\circ}2$$

The method of deriving the position of the polar axis from the rotational movement of equatorial markings does not seem to have been employed before. It has the advantage of giving a complete determination of both coordinates from the observations of a single opposition. Our result is in good agreement with that of Lowell and Slipher¹⁶ obtained from observations of the polar caps made in the years 1901–1911; which, reduced to 1925, is:

$$R.A. = 316^{\circ}0 \quad Decl. = +54^{\circ}2$$

According to both determinations the Ephemeris position needs only a small correction in the R.A. of the North pole.

W. H. Pickering,¹⁷ on the other hand, finds a quite divergent result; reduced to 1925 it is:

$$R.A. = 315^{\circ}2 \quad Decl. = +51^{\circ}8$$

His method of comparing the latitudes of certain markings derived at three different oppositions from drawings is open to two serious objections. Latitudes taken from drawings based on eye estimates are likely to be affected by systematic errors of a personal character. It is well known that estimates of the center of a round disk, for example, may be consistently too high or too low by a few percent even for an experienced observer. A change in the personal equation of Prof. Pickering between 1914 and 1922 would be sufficient explanation of the discrepancy. The other assumption on which Pickering's method rests is that most of his markings have not undergone any change in latitude during a period of 8 years and at entirely different seasons. But our measures when compared with older observations show, on the contrary, that considerable systematic changes must have taken place during the last ten or twenty years especially in the latitude of the northern boundary lines of some of the southern maria on which many of Pickering's points are situated. These have then all been affected in the

¹⁶ *Lowell Obs. Bull.* **2**, 28, 1912.

¹⁷ *Report on Mars* No. 33; *Pop. Astr.* **34**, 1926; *Harv. Ann.* **82**, 106.

same sense (advance toward the North). Pickering's result therefore hardly deserves any confidence as long as his observations do not cover a full cycle.

In his study of the perturbations of the satellites of *Mars* by the flattening of the planet H. Struve also derives the position of the equator of *Mars*, leading to

$$\text{R.A.} = 312^{\circ}6 \quad \text{Decl.} = +52^{\circ}8$$

for the position of the North pole (1925), a result that could not be reconciled with our numerous measures of markings.

9. AREOGRAPHIC LONGITUDES AND LATITUDES OF 228 SURFACE MARKINGS

For the final calculation of the areographic longitudes and latitudes of the measured markings the corrected constants of the second solution were employed, namely:

$$\begin{aligned} \text{Equatorial diameter of Mars} & 9''.178 \\ \text{Flattening} & .0113 \\ \text{Position of North pole R.A.} & = 315^{\circ}9 \text{ Decl.} = +54^{\circ}7 \\ \text{Zero correction to } y \text{ measures} & - .007 \end{aligned}$$

and on these values our catalogue is based. Designating with x'_e and y'_e the rectangular coordinates calculated with the improved constants, the equations (8) go over into:

$$(10) \quad \begin{aligned} x_0 - x'_e &= \cos(\lambda - \lambda_0) dL - \sin \beta' \sin(\lambda - \lambda_0) d\beta' \\ y_0 - y'_e &= \sin D \sin(\lambda - \lambda_0) dL + \{ \cos \beta' \cos D \\ &\quad + \sin \beta' \sin D \cos(\lambda - \lambda_0) \} d\beta' \end{aligned}$$

where $dL = \cos \beta' d\lambda$. For every point we have such a system of equations of condition which were solved for dL and $d\beta'$ by least squares solutions with the one simplification that the y coordinates were not used for the determination of dL , as in the second equation of (10) the coefficient of dL is always small. The areographic longitude (Table 6, col. 2) is obtained by applying the correction $d\lambda = dL \sec \beta'$ to the approximate value of λ used in the calculation of x_e and y_e , while the true areocentric latitude of the flattened ellipsoid (Table 6, col. 4) is found by adding the two corrections $d\beta'$ and $\beta - \beta' = -0^{\circ}.32 \sin 2\beta'$ (equation (7), page 29) to the approximate value of β' . According to this method the longitudes and latitudes were also derived for a number of points not used in the determination of the constants. Table 6 gives the results for a selection of the best measured or most important points; the others have been used only for the construction of the chart and can be read off from this about as accurately as they are determined.

To insure correct identification, all points of Table 6 were entered on two skeleton charts (Plate III, fig. 2, and Plate IV, fig. 2) together with their number (Table

TABLE 6
AREOGRAPHIC LONGITUDES AND LATITUDES OF 228 MARKINGS

No.	Longitude	Wt.	Latitude	Wt.	No. plates	Description*
1	1.3	6.1	+ 6.0	8.4	12	N.W. point <i>Sabaeus Sin.</i>
2	2.4	5.0	-26.3	6.6	8	
3	6.6	2.3	+21.4	1.8	5	
4	9.1	4.0	-42.2	4.8	7	
5	9.5	5.2	-19.0	8.2	10	
6	9.5	8.8	- 9.4	13.2	15	S.W. limit <i>Sabaeus Sin.</i>
7	10.6	3.2	+35.2	2.7	7	<i>Siloe F.</i>
8	11.5	2.4	+14.5	2.7	5	
9	12.5	0.6	-68.3	1.3	4	
10	12.7	8.1	- 2.8	12.2	14	W. limit <i>Sabaeus S.</i>
11	13.4	2.2	+18.5	1.7	6	
12	15.1	3.1	-61.9	2.7	7	
13	18.0	5.6	+11.1	6.7	11	<i>Oxia Pal.</i>
14	18.2	2.6	-26.3	4.1	5	
15	21.2	2.5	-47.1	3.4	6	
16	21.4	9.5	+ 5.6	12.0	14	Point of <i>Margaritifer S.</i>
17	21.9	2.4	+49.7	0.5	4	
18	26.4	3.3	-11.3	4.9	5	
19	26.8	1.7	+25.5	1.3	4	E. part <i>Niliacus L.</i>
20	28.1	2.6	-27.4	3.2	4	
21	29.1	2.9	-55.0	3.5	7	
22	36.1	4.7	- 3.3	6.4	9	<i>Aromatum Prom.</i>
23	36.5	4.9	+30.2	3.1	9	<i>Niliacus L.</i>
24	39.9	4.4	-27.0	6.6	8	<i>Protei Lac.</i>
25	40.2	3.2	-40.5	4.0	8	
26	41.5	3.3	-19.2	4.5	8	
27	41.9	2.6	-62.5	3.6	7	
28	43.6	2.5	+48.7	0.7	4	
29	44.4	1.6	- 3.2	2.4	3	N. limit <i>Aurorae S.</i>
30	46.1	3.7	+ 3.7	4.2	8	
31	46.6	3.0	+14.1	2.9	10	Inters. <i>Iamuna, Hydrates</i>
32	47.0	4.4	-12.5	8.1	10	<i>Auri Lac.</i>
33	52.0	2.9	- 9.7	4.1	8	Light spot, <i>Aurorae S.</i>
34	52.2	5.0	-42.7	6.9	10	<i>Aridus Lac.</i>
35	54.4	6.4	-25.8	11.9	15	
36	54.9	2.5	+34.3	1.5	6	<i>Craneum</i>
37	58.1	7.2	- 3.6	10.0	12	N.W. point, <i>Aurorae S.</i>
38	62.0	6.3	-11.8	10.5	13	W. limit, <i>Aurorae S.</i>
39	63.7	6.2	- 0.4	7.9	12	<i>Juventae F.</i>
40	64.4	3.2	-25.3	5.2	8	<i>Nectaris F.</i>
41	64.4	2.2	-62.2	1.7	4	
42	66.9	3.7	-18.7	5.5	8	
43	68.9	2.5	+11.3	3.2	7	<i>Lunae Lac.</i>
44	69.0	4.6	-67.8	5.2	13	
45	70.8	4.8	-35.5	7.1	10	
46	73.3	8.5	- 9.1	12.9	15	<i>Maeisia Silva</i>
47	74.3	2.4	+21.3	1.9	4	<i>Labeatis Lac.</i>
48	75.9	3.2	-23.7	4.4	7	
49	76.4	2.0	-34.7	2.8	3	N.W. limit, <i>Bosporus</i>
50	76.8	2.8	+ 0.5	3.7	7	<i>Messeis F.</i>
51	84.4	2.9	+ 8.7	3.1	7	
52	84.6	4.4	-45.0	5.9	9	<i>Ambrosiae Lac.</i>
53	84.6	2.8	- 5.1	3.8	6	E. part, <i>Tithonius Lac.</i>

* The terms east and west are used like on terrestrial charts: east in the sense of decreasing longitude, west in the direction of increasing longitude.

TABLE 6—(Continued)

No.	Longi- tude	Wt.	Lati- tude	Wt.	No. plates	Description*
54	85.8	1.3	-26.6	2.5	4	Center, <i>Solis L.</i>
55	86.7	5.3	-31.4	7.9	10	S. point, <i>Solis L.</i>
56	89.4	6.4	-20.8	9.7	11	N. point, <i>Solis L.</i>
57	91.9	1.9	+32.8	1.3	5	
58	92.2	1.8	-11.6	2.5	4	
59	92.9	4.4	-40.2	6.7	9	S. limit of <i>Thaumasia</i>
60	93.9	1.9	+45.9	0.7	4	
61	94.0	6.3	-7.1	9.4	12	<i>Tithonius Lac.</i>
62	97.5	2.6	+21.5	2.4	8	<i>Ascræus L.</i>
63	98.3	7.3	-27.9	10.8	12	W. point, <i>Solis L.</i>
64	99.9	2.4	-58.6	2.0	5	
65	104.7	1.7	-20.1	2.4	5	
66	104.9	5.0	-68.2	4.1	9	
67	105.2	6.4	-35.2	11.1	13	N.E. point, <i>Aonius S.</i>
68	107.0	3.1	-47.2	3.5	6	
69	109.0	6.7	-14.0	11.6	15	<i>Phoenicis L.</i>
70	109.2	5.0	-42.0	6.9	10	<i>Bathys L.</i>
71	109.4	1.5	-2.3	2.1	6	<i>Arsine</i>
72	109.7	3.9	+11.8	4.0	8	<i>Ceraunius</i>
73	112.9	2.5	+28.2	1.5	5	
74	114.6	4.0	-21.1	5.2	8	
75	119.4	0.9	+2.2	1.1	3	<i>Biblis F.</i>
76	120.9	1.4	-55.1	1.0	3	
77	122.1	6.2	-31.0	10.5	12	
78	124.1	6.4	-25.2	11.9	13	N.E. point, <i>Sirenum M.</i>
79	124.6	3.2	-49.6	3.5	7	
80	125.8	3.5	-6.5	4.3	8	Inters. <i>Sirenius, Eumenides</i>
81	126.3	3.2	+14.8	2.6	5	<i>Bandusiae F.</i>
82	128.5	2.5	+30.0	1.6	6	<i>Cyane F.</i>
83	130.3	2.2	-67.2	2.2	6	
84	131.0	6.7	-31.5	9.4	12	
85	134.2	5.7	-23.2	8.9	12	
86	135.9	2.6	-54.6	2.2	4	
87	136.5	2.7	+20.7	2.0	4	<i>Nix Olympica</i>
88	138.6	4.0	-7.3	6.0	10	<i>Nodus Gordii</i>
89	139.1	2.7	+5.0	3.1	6	
90	139.6	5.8	-27.1	8.5	10	S. limit of <i>Memnonia</i>
91	142.4	2.4	-40.0	2.5	3	N. end of <i>Thermodon</i>
92	143.3	5.9	-33.6	9.9	12	
93	145.6	1.5	+27.5	1.0	4	
94	145.7	3.0	-51.5	3.6	6	<i>Palinuri Fret.</i>
95	147.1	1.6	+16.8	1.5	5	<i>Memnonius L.</i>
96	150.6	2.2	+1.1	2.7	5	<i>Maricae L.</i>
97	152.0	1.4	+43.5	0.6	3	<i>Propropontis</i>
98	152.6	3.4	-10.5	4.7	9	
99	154.2	6.9	-21.0	11.0	13	<i>Gorgonis L.</i>
100	158.1	2.4	-60.6	2.8	8	
101	160.5	2.9	-70.8	2.2	6	
102	162.0	5.8	-3.4	7.8	9	
103	163.0	3.0	-53.8	3.3	8	
104	164.5	2.5	+5.2	3.7	7	<i>Ammonium</i>
105	164.6	1.5	-79.8	1.7	3	
106	164.9	2.6	-45.5	3.4	5	
107	171.8	2.1	-0.6	3.0	6	

* The terms east and west are used like on terrestrial charts: east in the sense of decreasing longitude, west in the direction of increasing longitude.

TABLE 6—(Continued)

No.	Longi- tude	Wt.	Lati- tude	Wt.	No. plates	Description*
108	172.0	4.8	-34.4	7.7	10	
109	172.3	6.8	-10.9	11.5	12	<i>Titanum Sin.</i>
110	174.3	4.9	-19.1	8.7	9	<i>Titanis Lac.</i>
111	176.6	1.1	-57.5	1.6	4	
112	178.7	1.9	-48.3	2.2	4	
113	178.7	3.8	-64.4	3.7	9	<i>Ulyxis Fret.</i>
114	179.3	1.1	+46.1	0.4	2	<i>Propontis</i>
115	183.6	1.5	-38.9	2.5	6	
116	183.6	4.5	-0.7	6.7	10	<i>Aquæ Apollinares</i>
117	187.1	8.9	-13.4	6.2	8	S. limit, <i>Zephyria</i>
118	188.9	1.4	-52.0	2.1	5	
119	189.5	1.2	-24.4	2.7	4	
120	191.6	1.5	+8.7	1.7	5	
121	196.7	4.2	+17.0	4.4	8	S.E. point, <i>Trivium Charontis</i>
122	201.9	4.3	-60.0	5.0	9	
123	203.1	6.5	-7.8	8.7	10	<i>Laestrygonis Sin.</i>
124	203.2	1.2	+35.6	0.6	2	<i>Hecates L.</i>
125	203.4	2.2	+1.0	2.9	8	
126	204.7	4.4	-30.8	6.8	9	<i>Scamandri Lac.</i>
127	205.6	3.7	-74.7	2.6	6	
128	206.8	3.5	-15.0	5.9	8	<i>Laestrygonis Lac.</i>
129	208.4	2.1	+21.7	1.6	3	S.E. limit, <i>Elysium</i>
130	208.5	2.6	-51.3	3.7	5	<i>Mare Chronium</i>
131	216.7	2.9	+41.2	1.3	4	
132	221.8	5.0	+10.2	6.0	8	<i>Lucrinus L.</i>
133	221.8	3.4	-22.7	5.0	6	
134	224.3	3.3	-15.7	4.5	6	<i>Cyclopus L.</i>
135	225.1	3.5	-6.3	5.2	7	
136	232.4	2.3	-75.5	2.5	5	
137	232.7	4.2	-31.0	7.8	10	<i>Cynia L.</i>
138	232.9	3.4	-51.0	5.2	8	<i>Tiphys Fret.</i>
139	233.3	2.5	+23.1	2.8	5	E. part, <i>Hephaestus</i>
140	233.4	3.4	+1.6	4.8	7	
141	237.5	4.8	-9.9	7.8	8	<i>Cimmerius L.</i>
142	238.2	1.7	+17.6	1.6	3	W. part, <i>Hephaestus</i>
143	239.2	2.4	+7.4	3.0	4	
144	250.5	3.0	-20.5	5.2	6	<i>Hesperidum L.</i>
145	251.8	2.6	-31.2	4.4	5	N. limit, <i>Ausonia austr.</i>
146	252.8	2.2	+3.5	2.9	4	<i>Minor L.</i>
147	253.4	2.6	-55.1	2.7	5	
148	255.7	1.7	+26.6	1.5	3	<i>Lethes L.</i>
149	256.2	2.2	+41.0	1.1	3	<i>Aquæ Calidae</i>
150	260.0	2.7	-2.7	4.0	5	N.E. point, <i>Syrtis Minor</i>
151	260.0	2.6	-40.0	4.1	5	E. point, <i>Hadriacum M.</i>
152	260.2	3.4	-63.7	3.2	6	
153	262.7	1.5	+14.0	1.4	2	<i>Tritonis L.</i>
154	263.4	1.9	-11.5	3.7	6	
155	267.0	2.9	-29.8	4.4	6	
156	267.3	2.7	-51.1	3.1	5	
157	267.7	3.4	-41.5	7.0	8	
158	272.7	2.4	-7.7	2.9	3	
159	273.0	2.5	+0.2	3.0	4	
160	276.7	0.6	+47.2	0.2	2	<i>Isidis L.</i>

* The terms east and west are used like on terrestrial charts: east in the sense of decreasing longitude, west in the direction of increasing longitude.

TABLE 6—(Continued)

No.	Longi- tude	Wt.	Lat- itude	Wt.	No. plates	Description*
161	278.0	3.3	-76.3	2.5	5	
162	278.0	1.5	+11.9	1.4	3	<i>Moeris L.</i>
163	280.3	2.6	-54.3	3.7	6	
164	280.7	3.9	- 0.8	6.9	8	S.W. point, <i>Libya</i>
165	280.8	2.4	+ 5.9	3.1	5	E. limit of <i>Syrtis Maior</i>
166	281.0	2.6	+33.1	1.3	3	<i>Nilus L.</i>
167	281.4	3.3	-33.0	5.8	8	
168	282.9	2.0	+23.9	1.9	3	N.E. point, <i>Syrtis Maior</i>
169	282.9	2.2	-13.7	3.9	4	<i>Lemurum L.</i>
170	286.8	2.1	-35.3	2.6	3	N.E. limit, <i>Hellas</i>
171	287.8	2.8	-62.7	3.1	6	
172	289.3	2.5	-43.7	3.4	7	
173	292.2	3.7	+ 3.1	4.9	6	<i>Maior Lac.</i>
174	294.0	3.0	-49.0	2.9	6	
175	294.9	2.2	+22.7	1.8	3	N.W. point, <i>Syrtis Maior</i>
176	297.7	3.6	-18.5	5.7	6	
177	298.0	2.4	-29.5	2.9	3	N. limit, <i>Hellas</i>
178	299.2	2.8	+43.4	1.3	4	<i>Coloe Palus</i>
179	299.6	2.4	+21.5	2.4	4	
180	301.2	3.8	+ 4.3	4.4	5	S.E. limit, <i>Aeria</i>
181	301.2	2.5	-43.6	2.7	5	Inters. <i>Alpheus, Peneus</i>
182	302.2	4.2	-68.8	4.4	8	
183	302.7	3.1	-10.9	3.9	4	
184	303.9	3.6	-58.8	4.0	8	
185	306.9	2.0	-51.3	1.8	4	S. limit, <i>Hellas</i>
186	307.0	2.6	- 4.2	3.6	4	<i>Hipponis L.</i>
187	307.6	3.8	+30.2	2.3	7	<i>Hipponitis Palus</i>
188	307.6	2.8	-20.4	4.0	4	
189	310.4	2.7	-31.0	2.7	3	N.E. point, <i>Yaonis L.</i>
190	311.6	3.1	- 0.1	4.6	6	N.W. point, <i>Deltoton S.</i>
191	311.8	4.6	-40.2	5.1	7	S.E. point, <i>Yaonis L.</i>
192	313.2	2.8	-10.8	3.9	4	<i>Hammonis Cornu</i>
193	314.6	3.7	-21.9	6.2	7	
194	316.4	1.9	+31.7	1.1	4	
195	317.0	2.1	-64.9	1.9	4	
196	317.1	3.1	-35.2	4.0	6	<i>Yaonis L.</i>
197	318.0	1.7	-79.0	1.8	4	
198	318.2	3.8	-14.4	6.2	7	<i>Hammonis Lac.</i>
199	321.2	2.2	-48.7	1.9	3	
200	321.4	2.9	-33.3	3.4	5	N.W. point, <i>Yaonis L.</i>
201	321.5	5.9	-73.5	7.3	13	<i>Novissima Thyle</i>
202	322.4	2.7	-52.6	2.3	5	
203	323.4	3.4	- 9.9	4.6	6	
204	324.4	3.7	-24.9	5.4	8	
205	325.7	1.2	+41.8	0.5	4	
206	326.8	2.3	-15.6	3.5	4	E. limit, <i>Deucalionis Reg.</i>
207	327.6	5.0	-46.3	6.2	8	
208	328.7	4.0	-19.3	6.0	7	
209	329.1	3.6	-61.1	2.8	6	
210	332.5	3.7	-25.3	5.4	7	<i>Erythraeus Lac.</i>
211	335.8	4.0	- 1.8	6.8	8	<i>Portus Sigeus</i>
212	338.6	3.7	+42.4	1.7	7	<i>Ismenius L.</i>
213	339.6	2.9	-35.4	4.0	7	
214	340.7	4.0	-11.4	7.3	8	S. limit, <i>Sabaeus Sin.</i>
215	341.5	4.0	-55.5	4.2	6	

* The terms east and west are used like on terrestrial charts: east in the sense of decreasing longitude, west in the direction of increasing longitude.

TABLE 6—(Continued)

No.	Longi- tude	Wt.	Lat- itude	Wt.	No. plates	Description*
216	343.7	1.4	-46.1	1.4	3	
217	345.0	3.7	-68.0	3.1	6	
218	346.0	5.5	-19.9	8.5	11	<i>Pandorae Fretum</i>
219	346.9	2.4	-31.6	2.6	5	
220	349.7	6.3	- 1.8	9.4	12	<i>Edom Prom.</i>
221	349.7	1.0	-27.8	2.5	5	
222	352.8	6.7	+ 5.3	8.9	12	N.E. point, <i>Sabaeus Sin.</i>
223	355.2	3.7	-48.2	5.3	8	
224	355.3	2.6	-36.8	3.2	6	
225	356.8	3.1	-10.6	4.0	4	S. limit, <i>Sabaeus S.</i>
226	358.7	4.0	+ 1.4	5.0	7	<i>Fastigium Aryn.</i>
227	358.8	2.7	+38.4	1.3	5	<i>Eulaei Lac.</i>
228	359.1	1.4	-60.4	2.3	6	

* The terms east and west are used like on terrestrial charts: east in the sense of decreasing longitude, west in the direction of increasing longitude.

6, col. 1). If a point is marked by an open circle, the measures refer to the center of a dark spot (oasis) or of a condensation in the dark areas, or they represent the intersection of two or several dark lines (canals), and in a few cases the centers of light spots or areas; in short, the open circles always refer to markings of a more or less symmetrical character. Measures of the boundary between dark and light areas, or the points of projections (caret, sinus, promontorium) are indicated by a cross or star. The weights of cols. 3 and 5 of Table 6 are those of the least squares solution; they represent the accuracy of the result in great circle measure. Col. 6 gives the number of plates on which the point was measured and the last column the description of the marking in the usual nomenclature wherever the identification seemed beyond doubt. The names were mostly taken from the chart at the end of Flammarion's book *La planète Mars*, vol. 2, or from the chart at the end of *Lowell Observatory Annals*, vol. 2.

The system of areographic longitudes, with respect to its zero point, is based on the longitudes of central meridian given in the *American Ephemeris* for 1924. If the *Fastigium Aryn* were adopted as zero point, a correction of +1°3' would have to be applied to the longitudes of Table 6. As this correction is small and may partly be due to errors or changes in this single point it seemed preferable to retain the system of the *Ephemeris*.

The probable error of unit weight was calculated from the residuals of the individual x and y measures; 32 markings with a total of 246 measures in each coordinate were for this purpose selected at random, being the first eight of every quadrant of longitude (excluding, however, those with less than 5 measures). These points should represent a fair average and give

Fig. 1

Fig. 2

Fig. 3. Drawings of the South Polar Cap and its Surroundings.
The circles represent latitudes -60° , -70° and -80° .

for the probable error of unit weight ϵ expressed in fractions of the planet's radius:

$$\begin{aligned} x \text{ coordinate } \epsilon &= \pm .0206 \\ y \text{ coordinate } &.0193 \\ \text{Mean } \epsilon &= \pm .020 \end{aligned}$$

The accuracy is practically the same in both coordinates; the four measures of one plate furnish the position of a marking with a probable error of 1 per cent of the diameter, or $\pm".24$. This probable error seems rather large compared with the accuracy of photographic star positions. It should not be forgotten, however, that the surface markings of *Mars* are of quite different character from star images; they are mostly faint, difficult to identify and to measure, and many of them are unsymmetrical. The short exposures of *Mars* are also more subject to atmospheric distortions of the image, while in the longer exposures of star images these distortions nearly balance each other in all directions.

Expressed in degrees of great circle at the center of the disk the probable error of unit weight is

$$\epsilon = \pm 1^{\circ}.1$$

and the probable errors of the catalogue positions are calculated from the weights p (Table 6, cols. 3 and 5) by the formulae:

$$\begin{aligned} \text{probable error of longitude} &= \pm \frac{1^{\circ}.1}{\sqrt{p}} \sec \beta \\ \text{probable error of latitude} &= \pm \frac{1^{\circ}.1}{\sqrt{p}} \end{aligned}$$

The average weight of the catalogue positions is 3.5 in longitude, 4.4 in latitude, and the corresponding probable errors are $0^{\circ}.6$ and $0^{\circ}.5$. A few of the best observed markings have probable errors as small as $0^{\circ}.3$ which is equivalent to 11 miles on the surface of *Mars*. For points north of latitude $+30^{\circ}$ the latitudes are very uncertain because of the proximity of these markings to the limb. Points near the South pole are comparatively better determined, as they are visible on many plates and as their latitudes are also obtained from the x measures near greatest eastern and western elongation.

The advantage of the photographic method for measuring the positions of Martian surface details does not lie so much in the increased accuracy of an individual measure as in the ease and rapidity with which numerous measures are accomplished and in the possibility of eliminating systematic errors by making the measures in different positions of the image. For symmetrical markings like the many dark spots and canal intersections it may confidently be expected that our measures are free from systematic errors. It is, however, doubtful whether the same could be said for

points on the boundaries of dark and light areas. These boundaries appear generally as somewhat gradual transitions and the limit must be set arbitrarily (the greatest gradient of intensity was chosen as a rule). The fact, that the measures of the limb of the planet, made in a similar way, depend little on the exposure time or contrast and show no evidence of sensible systematic errors seems to justify the anticipation, that the same is true for the boundary lines, wherever a sharp boundary really exists.

10. THE CHART OF MARS

From the observational material obtained at the 1924 opposition a chart of the surface of *Mars* was prepared by pencil drawing in two parts. The first (Plate III, fig. 1) presents the equatorial regions from latitude -65° to $+50^{\circ}$ on the Mercator projection, the second (Plate IV, fig. 1) the Southern hemisphere between latitude -30° and the South pole in stereographic projection.

A preliminary draft of both charts was based on the measures and sketches of 13 plates made during the winter 1924-25. During the second series of measures (autumn, 1925) all images measured for diameter (Table 2) were examined on the original negatives with the microscope and compared with the preliminary charts, making notes about any corrections or additions required. A similar comparison was made with all the sketches obtained by visual observation. The definitive charts as reproduced were then completely redrawn. All the points of Table 6 as well as numerous others less frequently measured were first entered according to their longitudes and latitudes on the reseau of the charts. The markings were then executed with the help of the preliminary charts and the notes concerning their improvement. Greatest effort was made to have the chart resemble the photographs as closely as possible in general appearance. The relative intensities of the shadings were estimated on enlarged positives, making a compromise whenever they seemed to vary with the position on the disk. As some slight changes have undoubtedly taken place on *Mars* during the period of observation, preference was always given to the observations nearest to opposition (August 20-September 21). When the chart was completed, it was again compared with all drawings and photographs until the observer was satisfied of its correctness.

By careful comparison of about 150 of the best photographs it was possible to eliminate the effects of the plate grain as well as lack of definition or atmospheric distortion in some parts of the images. No detail was entered on the chart unless visible on several photographs or confirmed by visual observations.

While the chart is essentially a combination of all the photographs, it was, of course, necessary to enhance the finer details, especially the spots and lines of the network, in order to make them easily visible.

Practically every detail observed visually can be found on some of the photographs, but the latter may show only a trace of something without revealing its character or appearance and the visual observations were a great help in the representation of the fine structure, such as sharpness, width, regularity, etc., of boundary lines or canals. On the other hand many markings are quite satisfactorily shown by the photographs which were not noticed in the visual observations. This is especially true of the details in the dark areas and in the region around the South pole. While the eye is perhaps more sensitive for picking up dark lines and spots on the normal yellow-orange colored surface, the photographs as a whole give better resolution in the dark areas and in close proximity to the limb.

Our chart of *Mars* should, of course, not be considered as a permanent map of the planet; it is intended only as a representation of the surface for the period of observation. If it has been constructed with such care and precision, this was principally for the purpose of subsequently studying the changes depending on the seasons and other causes. The favorable weather conditions on Mt. Hamilton and the use of the photographic method made it possible to accumulate sufficient observations for a detailed chart in the short time of one month. The Martian season to which our results apply is that immediately preceding the winter solstice of the Northern Hemisphere corresponding in our terrestrial calendar to the period from November 26 to December 16 (Pickering's Martian Dates November 22–December 2). The polar cap, on account of its rapid variations, is not entered on the chart, but is represented by separate drawings for each day of observation (Plates IV and V).

In regard to general features our chart is in good agreement with those of other observers; there are, however, notable differences in many details, most of which are undoubtedly peculiar to the 1924 opposition. Much discord still prevails concerning the character and interpretation of the surface markings of *Mars* and it seems inevitable to take up the discussion of these problems on the basis of the visual and photographic observations with the 36-inch Lick refractor, especially as many years have elapsed since this excellent instrument was used for the study of *Mars*. It must be emphasized, that before the 1924 opposition the writer had never made any systematic observations of *Mars* and was not familiar with the Martian topography. The present description was therefore made as of something new or unknown and could not have been influ-

enced by any knowledge of the appearance of *Mars* in smaller telescopes.

11. THE DARK AREAS OF MARS

The largest part of the surface of *Mars* (especially the Northern hemisphere) is of fairly uniform brightness and of a characteristic yellow-orange color: we may call it the normal surface. It corresponds to the white background of our chart. Among the different classes of markings detaching themselves from this background we take up first the extended dark areas (generally designated by the term "mare") which with irregular and partly connected outlines cover a large part of the Southern hemisphere. In the 36-inch refractor they appear of a distinctly blue-green tinge. This color estimate is perhaps enhanced by the contrast with the normal surface, but it is independently supported by a comparison of the photographs taken with the red and yellow filters. If both are obtained on the same plate and if the exposure times are so chosen that they have equal intensity for the normal surface, then the dark areas are darker on the red images than on the yellow ones. Remembering that the yellow photographs are made with wave-lengths 5300–5900 Å. (green to orange) while the red ones utilize only a narrow interval (5900–6100) in the orange, our observation shows that the dark areas reflect relatively more light of the shorter wave-lengths or more green light. Of course it is desirable that such color determinations be made on a numerical photometric basis, but even the qualitative comparison of the two filters is quite unmistakable.

None of the larger dark areas was found to be of uniform shading. On close examination the photographs (especially those of the red filter) reveal a great amount of structure in them, consisting principally of dark spots and bands and lighter areas or passages; many of these were confirmed by visual observation. This circumstance excludes the interpretation of the dark areas as regions covered by deep water and furnishes evidence for the nonexistence of larger seas or oceans on *Mars*.

Some of the boundaries of the dark areas appear quite sharp, especially the northern limits of *Erythraeum M.*, *Sirenum M.*, *Cimmerium M.*, and the western limit of *Syrtis Major*, while *Sabaeus Sin.* presents a sharply bounded area all around. In many places, however, the dark areas fade out in gradual transition to lighter areas without any marked limits. The depth of shading also differs very widely; the northern part of *Syrtis Major*, *Tyrrhenum M.* with *Syrtis Minor*, *Sirenum M.*, and *Sabaeus Sin.* were estimated to be the darkest. Between these and the normal surface practically every intermediate step is represented. Large

areas of very light shading occur quite outside of the "Mare" as e.g. in the region of the *Ganges* and S.W. of *Nix Olympica* (87).*

When our chart is compared with those of other observers made at former oppositions a considerable difference in the latitude of the sharp northern boundary of *Sirenum M.* and *Cimmerium M.* is immediately noticed. On our chart these dark areas extend 10° – 15° farther north and appear correspondingly wider. A real change in this boundary line must have taken place as so large differences could not be accounted for by errors of observation; this is in agreement with W. H. Pickering's¹⁸ statement concerning the changing latitude of *Titanum Sin.* It appears then that the dark areas are not quite permanent in outline and extent besides showing some well known variations in shading.

It is hard to find any hypothesis that can be reconciled with the observational data except the assumption that the dark areas are regions covered with vegetation. Not only is this in harmony with the observed color, but various forms of plant life and varying density of growth can account for the different degrees of shading. Climatic conditions and available supply of moisture, partly depending on the seasons, partly progressing over longer periods, will greatly influence the development of vegetation and may thus lie at the origin of the changes observed in the dark areas.

12. THE NETWORK (CANALS AND OASES)

The results of our observations as embodied in the chart indicate the existence of a complicated network of dark lines and spots covering the whole surface of the planet, the dark areas as well as the normal surface. Visual observers have paid most attention to the structure of this network in the latter regions, where it is most striking. There the lines appear rather narrow, so that the term "canal" has been applied to them while the spots, relatively small and well defined, have received the designation of "oasis" or "lacus." A few observers like Lowell and Douglass and others already have noted numerous canals and oases in the dark areas, and our chart shows the network equally well pronounced in these; with the difference, however, that here the lines often become broad diffuse bands and the dark spots appear as condensations of shading without any sharp edge, so that we might more appropriately speak of a "framework." Despite these differences there is good evidence that the framework of the dark areas is of the same character as the network of canals and oases on the normal surface. First, we find in both the same general design as to size and

arrangement of the meshes; the lines running most frequently between dark spots or radiating from them. Secondly, the whole network is one continuous system; it does not stop at the boundaries of dark areas, and many lines can be traced on a course leading through light and dark regions indiscriminately. Thirdly, there are instances where a network line may be narrow like a canal at one time and widen to a broad band at another time (*Nectar*, *Cerberus*, *Thoth*, etc.). Most convincing is perhaps the case of *Pandorae Fretum* which in 1924 appeared as a light area with a network of faint canal-like lines as shown in the chart. At the 1926 opposition this whole region presented the aspect of a dark area and these same lines then took the character of the more broad and diffuse bands typical of the dark areas.

The network of our chart coincides to a great extent with the canals and oases drawn by other observers. These markings having been the subject of a widespread controversy, a closer description of their appearance may be of interest. Before the 1924 opposition the observer had never seen any of the canals and entertained a rather critical point of view concerning their reality. But even on the first observing night it did not seem possible to make a faithful drawing of what was seen in the 36-inch telescope without entering on it some of the more prominent network lines which like *Araxes* (69–78), *Eosphoros* (54–69), *Eumenides* were among the most easily visible markings. With increasing observing practice more of the canals were recorded, and at the same time a careful examination and comparison of the photographs plainly revealed parts of this network. On a good night the more prominent canals were steadily visible while many others appeared only at intervals during the moments of best definition. The principal gain in observing practice was not in seeing more of the lines, but in remembering and recording on the drawings what was seen. Some of the denser parts of the network, like the regions between *Nodus Godii* (88) and *Titanum Sin.* (109) or that south of *Trivium Charontis* (121), or that of *Tithonius Lac.* made, most of the time, the impression of a slightly shaded area. But when, for a moment, the definition improved they suddenly resolved into a maze of well defined lines, too complicated, however, to be retained by the memory from such short flashes, even if they repeated themselves. The observer has thus never been able to satisfy himself of having correctly represented the region of *Nodus Gordii* (88) e.g. as seen at the few glimpses under the most favorable atmospheric conditions.

The question of the canals of *Mars* is often treated as if all these objects were of the same character and appearance; yet nothing is farther from the results of our observations. The use of the same technical term

* The numbers in brackets refer to those of the skeleton charts (Plate III, fig. 2 and Plate IV, fig. 2).

¹⁸ *Report on Mars* No. 5, *Pop. Astr.* 22, 303, 1914.

canal for all these various markings has perhaps led to such a misconception; it is partly for this reason that the writer prefers to speak of a network, partly because the structure of the dark areas is not "canal-like" at all.

Not only do the lines of the network differ widely in visibility, some being of the most easily visible, others among the most difficult details, but similar differences exist in regard to width, definition, uniformity, etc. That the canals always are somewhat diffuse on the photographs is undoubtedly due to the grain of the plate, but even in visual observations under the most favorable atmospheric conditions the canals did not as a rule present the appearance of fine, sharp, uniform, straight lines as they are described by Schiaparelli and Lowell, and in many cases the lines have a well marked width. *Nectar* (40-63), *Cerberus*, *Styx*, *Thoth*, with widths of 250 to 400 miles (400-650 km.), might at the 1924 opposition be called broad bands and classified with the dark areas. Others like *Araxes* (69-78), *Coprates* (38-46), *Eumenides*, etc., fitting better the description of canals, have still a noticeable width of 60-130 miles (100-200 km.). Even the fainter lines for which the widths could not be estimated with certainty made the impression of diffuse, hazy shadings. A few like *Ganges* appeared rather as the edge of slightly shaded areas. When comparing many photographs it is occasionally noticed that a certain part of a canal is better visible on most of them than the rest, thus indicating that the same canal changes in intensity along its course, and the observer does not feel certain that there are not cases where they break off entirely before reaching an endpoint (oasis or dark area).

Strongly curved canals are rare and a certain directness or straightness of line predominates; sharp changes of direction are generally marked by an oasis or lacus. The straightness is, however, more striking in visual observations than on the photographs; there can be little question that the visual observer has the tendency to smooth out minor irregularities and line up the markings. It should be stated that on the photographic negatives, where the canals appear as light lines on a dark background, they are equally well if not better shown than on enlarged positives. On the other hand, dark lines on a light background (corresponding to light lines in the dark areas) are rarely picked up on the negatives except as broad passages. As examples of canals well visible on the reproductions of Plates I and II the following may be cited:

Plate I: Fig. 4: *Gehon*, *Oxus*. Fig. 7: the fairly sharp straight line connecting *Juventae Fons* (39) with *Aurorae Sin.* (37). Fig. 10: *Coprates* (38-46), *Araxes* (69-78), *Eumenides*, the line (47-69). Fig. 12: *Araxes* (69-78), *Eumenides* and *Elison* (78-88) form a well marked triangle of straight lines; (81-102) is broad and strong.

Plate II: Fig. 2: *Tartarus* (102-132), (99-102) and (102-114). Fig. 6: *Cerberus*, *Eunostos* (132-139), *Pactolus* (132-148), *Aethiops* (141-142), *Hyblaeus* (131-139). Fig. 7: *Cerberus* (132-140), *Aethiops* (141-142), *Triton*, *Thoth*. Fig. 10: *Phison*, *Euphrates*, *Astaboras* as well as the canal (190-227) are faintly visible.

The network in the dark areas is best illustrated by Plate I, figs. 5, 8, 10, 11 and Plate II, fig. 7.

Before taking up the interpretation of the network it is necessary to decide whether the canals are real surface markings or whether their observation is due to optical illusions as some astronomers have asserted. The issue is perhaps more clearly defined by the question: Are there features on the surface of *Mars* which are arranged in spots and lines forming a network, although their fine structure may in reality somewhat differ from the smooth lines observed? Or the alternative: Are the canals merely lines which the eye, observing with insufficient resolution and magnification, picks out from a slightly irregular granulation of the surface, while the real markings have no network character at all?

A. Köhl¹⁹ has recently investigated this problem in the light of his theory concerning the contrast effects in telescopic diffraction images. He comes to the conclusion that the surface of *Mars* in reality is probably covered with numerous fine, sharply defined details too small for the resolving power of the telescope. The transitions between areas where these details are of different density produce in the eye of the observer the optical-physiological effect of lines of contrast, most of which lie below the limit of perception. At certain places, however, between just resolvable planetary markings they are reinforced and become visible as "canals." Köhl illustrates this effect by cutting a printed page to circular shape, placing it on a black background and painting on it a few gray spots as well as a larger gray area with pointed projections. If this disk is seen at such a distance that the details of the print disappear, some faint dark canal-like lines are noticed produced by the irregular distribution of the printed letters, running between the gray spots and the projections of the gray areas.

This experiment is of great interest for the correct interpretation of observational data and may have an application to some of the finer and more difficult canals, but it does not fit the case of the Martian network in general. In the first place, it starts from the erroneous conception that the canals are all similar in visibility and character, which we have already dismissed as being far from the truth; and the faint contrast lines of Köhl's figure do not come anywhere near showing the variety of intensities and widths exhibited by the network lines of our chart. In the second place,

¹⁹ *VJS der Astron. Ges.* 59, 196, 1924.

Drawings of the South Polar Cap and its Surroundings.
The circles represent latitudes -60° , -70° and -80° .

the visibility of the contrast lines (Kühl's fig. 2 and 3) is far inferior to that of the stronger canals on our photographs. In the third place, the observations do not corroborate the idea that the canals become noticeable thanks to dark markings (spots or projections) at their ends, and our photographs show many canals interrupted by the edge of the disk (see *Eumenides* on Plate I, figs. 9 and 10) or ending in spots which are no stronger than they themselves. Finally, Kühl overlooks the fact that the network also covers the dark areas, and the broad bands in these can certainly not be treated as contrast lines; yet we have given strong reasons above, why the framework of the dark areas must be of similar topographic character to the canal network of the light areas.

Nobody examining our photographs can doubt the reality of markings like *Nectar* (40-54), *Cerberus*, *Thoth*, *Nasamon* (160-168); if seen at the 1924 opposition alone they would probably not be classified among the canals. But at other oppositions these same objects appeared as faint lines like most of the other canals. Should we then admit the reality of such a marking at one opposition when it is strong and reject the same marking as an illusion at another opposition when it is faint? Even if we were willing to drop the fainter canals as optical illusions it would be difficult to draw the line between real and illusory canals since the network contains lines of every degree of visibility from the strongest to the faintest ones. All evidence furnished by direct observation or deduction, it seems to the writer, supports the claim that most parts of the Martian network must be real surface features, although it is possible that a few of the faintest lines may be illusions due to contrast effects.

Some of the students of *Mars*, notably Lowell, have made the assertion that the canal network of *Mars* is of such striking geometrical regularity that it cannot be explained as a natural phenomenon, that it must be artificial, the work of intelligent beings. Our representation of the network can hardly support such a conclusion; it presents considerable irregularity and does not make the impression of artificiality. In some places the lines are closely crowded, intersecting without apparent system, in other parts the meshes are wide. Occasionally several lines cross each other without passing through the same point. Even the lines themselves are diffuse and not always uniform. The observer is under the impression that the network is drawn with rather too great regularity on the chart; many of the smaller irregularities could not be ascertained with sufficient certainty; it is one thing to notice slight irregularities in a line and another thing to represent these correctly in a drawing. The writer is therefore inclined to interpret the network as natural features of the topography of *Mars*.

It was not possible to obtain any estimate of the color of the canals from visual observations. A comparison of the yellow and red photographs taken on the same plate, however, shows that the canals behave like the dark areas, i.e. they are relatively darker on the red photographs, and we conclude from this fact that they are probably of the same blue-green tinge as the dark areas. The hypothesis that the latter are regions covered with vegetation then requires that the network is also being made visible by vegetation while the framework in the dark areas would indicate places where the vegetation is densest. This view is supported by the temporary broadening of certain canals like *Nectar*, *Cerberus*, *Thoth* into bands resembling the dark areas and further by the evident relationship of the network to the outline of the dark areas. On our chart the network appears like the skeleton of the dark areas, the latter forming projections (sinus, caret) along the lines, while in the open spaces of the meshes the light areas often advance into the dark ones (promontories).

There remains now the question, why in the light regions of the normal surface vegetation should be confined to the spots and narrow lanes of the network and why in the dark areas it should be most abundant there. The view that the network follows natural geological formations of the crust of the planet is perhaps the most obvious, and one would in the first place think of depressions of the surface in which moisture accumulates and where the temperature is higher, both factors favoring growth of vegetation. There is, however, a possibility that other geological features such as faults or volcanic cracks are responsible for the canals. It cannot be denied that the system of valleys on the Earth is very different from the Martian network, but there is no reason why the two must be similar. A comparison of the Moon and the Earth gives a vivid illustration of how different the surface formations of planetary bodies may be. In regard to size, mass, force of gravity at the surface, scarcity of water, density of atmosphere, *Mars* takes a position somewhat intermediate between the Earth and the Moon, and it would therefore be hard to predict what its surface structure should be.

Unfortunately, our knowledge about elevations and depressions on *Mars* is very limited. Observations of the terminator are difficult on account of the twilight effect and because they can only be made when *Mars* is at greater distances. One striking projection at the terminator was observed visually (1924, November 15, 6^h40^m to 8^h30^m Pac. S. T.) over the region of *Argyre*; being of large dimensions and long visibility it undoubtedly represented a cloud phenomenon as such have been observed before. Of more interest would be the smaller irregularities of the terminator for which

all our photographs were carefully scanned. With the gradual fading of illumination the terminator appears faint and diffuse on the photographic images and is not susceptible of accurate measures. Only eye estimates of the deviations from its normal elliptical shape could be made and led to the following notes:

Plate	Date	Projections	Defects
425	Sept. 26.706	<i>Zephyria, Electris,</i> Region E. of <i>Tri-</i> <i>vium Charontis</i>	<i>Chromium M., Cim-</i> <i>merium M.</i> (slight)
427	26.830	<i>Ausonia, Aethiopis</i> (plain)	<i>Cimmerium M.,</i> <i>Tyrrhenum M.</i> (slight)
428	29.701	<i>Phaetontis, Electris</i> (slight)	
438	Oct. 8.705		<i>Lunae Lac.</i> (47)
439	8.732	<i>Thaumasia</i> (plain), also <i>Ophir I.</i> betw. <i>Lunae L.</i> and <i>Tithon Lac.</i>	
440	11.716	<i>Protei Reg.</i>	<i>Aridus Lac.</i> (34)
441	12.647	<i>Argyre</i> (plain)	<i>Erythraeum M.</i>
443	12.763	<i>Thaumasia, Thyle I.</i>	

It will be noticed that the protrusions all refer to light regions, the defects to dark ones which is indeed in harmony with our assumption. The evidence is, however, not as good as it might appear, since the gradual fading of illumination and the photographic irradiation must produce a similar effect. The latter can be tested at the limb where it should be increased by the greater contrast. The original negatives* on the contrary show the limb to be much smoother than the terminator, so that at least a part of the observed irregularities may be real, indicating higher levels for the light regions, lower levels for the dark areas and the network. This also agrees with Lowell's observations.

Another source of information concerning elevations on *Mars* is furnished by the melting of the polar cap. It will be shown later that this melting process seems to progress more rapidly along the lines and near the spots of the network. A higher temperature is thus suggested for the network, and this most likely has its cause in lower levels.

No duplication or gemination of canals was observed either visually or photographically. Of course there are a few cases where lines run parallel or nearly so for some distance; but they are neither close enough nor sufficiently frequent to attract special attention. It must, however, be stated that the period of observation falls into the Martian season which according to Schiaparelli is unfavorable to duplication, and the present observations cannot furnish any valid proof against its occurrence.

* On the illustrations of Plates I and II the irregularities of the limb are much enhanced by the process of reproduction, while the real terminator is hardly visible.

13. WHITE SPOTS AND AREAS

Besides the South polar cap a number of spots and areas were observed as being lighter in shade than the normal surface and presenting a decidedly more whitish appearance. The most remarkable of these objects was a circular spot at the place where Schiaparelli in 1879 detected *Nix Olympica* and for which we have therefore adopted the same name. The first photographs favorable for this region were taken on August 21, and on some of these a small area is noticeable, surrounded by dark network markings, but hardly any brighter than the normal surface.* On August 22 (see Plate I, fig. 12) *Nix Olympica* stands out as a uniform white spot of 10° (360 miles, 580 km.) diameter but much less brilliant than the polar cap. Its appearance remained the same on photographs of August 23 and 24 (see Plate I, fig. 11) and a few of the best images still show a trace of it visible on August 28 close to the limb. The same spot was also noted on three sketches made by visual observation on August 23, 24, 25 with a diameter of about 6°; but the visual estimate is less reliable than the photographic measures. When the region came to view again in September no white spot could be detected either visually or photographically. *Nix Olympica* then appears to have persisted for a period of at least six days with a sharp outline, constant size and identical location (the photographic measures of its center on four days shows an extreme range of only 2°). No appreciable diurnal variation was evident; the spot was well visible not only in the forenoon hemisphere but as late as 2 hours past the central meridian. Mr. Wright having kindly allowed me to examine his plates, it is of interest to state that the white spot does not show on the ultraviolet images but is well marked on the infra-red ones. This circumstance as well as the invariability in position and outline leaves little doubt that *Nix Olympica* in 1924 was a surface phenomenon. One might think of a frost or snow deposit if the brilliancy were not rather low for this.

The other whitish markings were observed closely nestling toward the northern boundary of the southern maria. Two elliptical white areas to the east and west of *Titanum Sin.* (109) were seen during most of the observing period (August 20–24 and September 21–26). The first of these lying in *Memnonia* stretched along the north-eastern boundary of *Sirenum M.* from *Titanum Sin.* about 10° to the south-east. A trace of it is visible on Plate I, fig. 11. The second, situated in *Zephyria* close to the northern limit of *Cimmerium M.* was larger and more pronounced; it is shown in Plate II, figs. 1, 2, 3. Varying somewhat in size it extended at its maximum from *Titanum Sin.* (109) to *Laestri-*

* The reproduction of Plate II, fig. 1 does not give good definition in this part of the disk.

gonum Sin. (123) with a width of nearly 10° . A smaller white spot (ca. 7° diameter) was occasionally noticed right north of *Titanum Sin.* (109). A similar marking (10° – 12° diameter) seemed to overlie *Edom Prom.* (220) on October 8 and November 15.

Wright²⁰ was the first to draw attention to the existence of “impermanant white configurations” exhibited by the violet and ultraviolet photographs, which he interpreted as “clouds of fine haze.” He found these quite persistent along the borders of *Sirenum M.* and *Cimmerium M.*, and they are undoubtedly identical with the white areas observed in the same position visually and on yellow photographs. Wright sought to distinguish between objects of this kind and the extremely bright temporary patches on the disk of *Mars* sometimes seen with the telescope. As a result of our combined observations it appears then that we have to distinguish two classes of bright markings. The first, like *Nix Olympica*, are not visible on violet or ultraviolet photographs while fairly strong on yellow or red images; they must be on the surface of *Mars* or immediately above it. To this class the great white spot observed by Slipher²¹ in 1922 seems to belong. In the second class we have the objects described by Wright which are more striking on violet or ultra-violet photographs, but also noticeable by visual observations; they are probably phenomena of higher atmospheric levels.

A rather exceptional formation for *Mars* is the small light spot in *Aurorae Sin.* (33) which was well observed visually on September 1 and 2 with magnification 520 and drawn as of 3° or 4° diameter; it is also shown on many of the photographs (Plate I, fig. 8), but did not distinguish itself by any peculiar color. Attention may here be drawn further to the brightness of *Ophir I.* during the period August 26–September 2. Southwest of *Fons Juventae* (39) and west of the *Ganges* it detaches itself as a sharply defined light band (see Plate I, figs. 7 and 8) enhanced somewhat by the contrast with the slightly shaded areas on both sides.

14. THE SOUTH POLAR CAP

The increase in contrast necessary for the reproduction of the photographs in Plates I and II has suppressed most of the details in the polar cap. The original negatives, however, do not suffer from this defect and are very well suited for a study of the seasonal changes in the South polar regions. From each of the forty plates a sketch of the polar cap was made with the aid of the microscope and a number of points were measured along its border and in its surroundings. Computing the areographic longitudes and latitudes and plotting the measured points on a chart

²⁰ *L. O. Bull.* **12**, 61, 1925.

²¹ *Publ. A. S. P.* **34**, 215, 1922; *Pop. Astr.* **33**, 593, 1925.

reseau in stereographic projection, the 26 polar cap charts of Plates IV and V were prepared by pencil drawing. The latitude circles are given for intervals of 10° and the charts cover the area from -60° latitude to the pole. Combining the results of the different plates taken on the same night, only one chart was made for each day of observation.

The eccentric position of the South polar cap is easily noticed on the drawings. The many irregularities of the outline render a determination of its center rather uncertain.

Period	Center of South polar cap	
Aug. 20–Sept. 12	$\lambda = 55^\circ$	$\beta = -83^\circ$
Sept. 22–Oct. 12	45	–87

In looking over the photographs of Plates I and II the poor visibility of the polar cap on figs. 2, 4, 5, 6, 7 of Plate II is surprising, while on later photographs (Plate I, figs. 1, 2, 3) it appears again of normal strength but smaller. It might be suggested that a temporary obscuration of the polar cap by atmospheric cloudiness had taken place between September 11 and September 26. On closer investigation, however, this suggestion must be dropped. Of the two series of photographs taken on September 11, the earlier one (Plate II, fig. 11, $\lambda_0 = 283^\circ$) shows the polar cap considerably weakened, the later one (Plate II, fig. 9, $\lambda_0 = 318^\circ$) again at normal strength. On September 26 the reverse is the case: polar cap normal on earlier plate ($\lambda_0 = 141^\circ$), faint on later plate ($\lambda_0 = 184^\circ$). This makes it evident that the visibility of the polar cap depends on the longitude of the central meridian and not on the date of the observation. For central meridians between 160° and 280° the South polar cap on account of its eccentric position and elongated outline must appear smaller and situated close to the limb, and in these longitudes it is moreover bordered by light areas. The oblique position of the surface to the Sun's rays and to the direction of view of the observer combine with the increased absorption in the Martian atmosphere so close to the limb in robbing the polar cap of its normal brilliancy. Only on the best photographs taken in these longitudes is the real polar cap clearly shown, detached from the surrounding light areas, as a small spot close to the limb; in visual observations it was always distinctly visible.

When the polar cap is turned toward the observer, there is hardly any noticeable difference between the yellow and red photographs with respect to the relative intensity of the polar cap, compared to the normal surface; perhaps the cap might be estimated just a trifle stronger on the yellow images. For central meridians between 160° to 280° , however, where the polar cap is close to the limb and small, it is considerably fainter on the red images. This is probably

related to the fact that the red photographs of *Mars* show a marked fading in the brightness of the disk as the limb is approached, while the yellow images present a more uniform disk with a sharper edge. As to size and outline, the polar cap appears pretty much the same in both colors.

The 26 charts of Plates IV and V give a good illustration of the way in which the South polar cap is gradually receding. The outline of the cap is very irregular with many projections and indentations; these are most numerous during the period August 20–September 13 and do not seem to be of a temporary nature, but often persist for many days. The projections or lobes as a rule are directed toward light areas. One of the most prominent of these, in longitude 150° (August 20–29), points toward *Thyle I*; others in longitudes 90° and 40° advance toward *Dia* and *Argyre*. The projection of *Novissima Thyle* (longitude 320°) is the entrance of a light passage leading toward *Hellas*. The indentations all occur near dark spots or where network lines enter the cap. One of these, at longitude 70° south of the spot (44) is well visible on Plate I, fig. 8. Another indentation at longitude 170° first (August 20) found south of the point (101) gradually recedes along a dark broad band toward (105). One cannot avoid the impression that the polar cap adapts itself closely to the topographic features of the planet and must be on the surface; our observations thus support the widely accepted hypothesis of a region covered with snow or ice, melting under the influence of the Sun's rays. This is not in contradiction to Wright's work, who finds very strong images of the polar cap in the ultra-violet, which he interprets as representing an atmospheric phenomenon. At the same time he admits the existence of a surface cap showing on infra-red photographs, and it is evidently with the latter that we are concerned in our yellow and red photographs. There does not seem to be anything unreasonable in the assumption that the melting snow covered area is associated with peculiar atmospheric conditions. These also seem to affect the visual observations to some extent, more than the yellow photographs. It may be due to this fact that the different parts of the cap were often of unequal intensity, and that some of the protruding lobes at its border were noted (visually) for exceptional brilliancy.

The observer who compares the apparent size of the polar cap from day to day finds its shrinking to progress very unevenly, as illustrated in Table 7, which gives the diameters of the South polar cap measured on the photographs at right angles to the central meridian. As no suitable photographs were available after October 12 the last five data were taken from later drawings made visually and are based on eye estimates.

TABLE 7
APPARENT DIAMETERS OF SOUTH POLAR CAP

	Date	No. plates	Central meridian	Diameter
1924	Aug. 20	1	184°	24°
	Aug. 21	2	154	28
	Aug. 22	2	121	28
	Aug. 23	2	140	26
	Aug. 24	2	112	30
	Aug. 25	1	105	29
	Aug. 26	1	88	26
	Aug. 28	2	78	28
	Aug. 29	1	69	27
	Aug. 30	1	54	27
	Aug. 31	2	52	24
	Sept. 1	1	48	27
	Sept. 2	1	37	25
	Sept. 4	2	25	22
	Sept. 7	2	338	21
	Sept. 8	1	337	23
	Sept. 11	2	300	19
	Sept. 13	1	294	17
	Sept. 15	1	253	15
	Sept. 21	2	238	11
	Sept. 22	2	183	9
	Sept. 26	1	140	14
	Sept. 29	1	111	16
	Oct. 8	2	34	15
	Oct. 11	2	348	15
	Oct. 12	1	12	15
	Oct. 18		251	(18)
	Oct. 22		215	(16)
	Oct. 30		140	(9)
	Nov. 1		118	(9)
	Nov. 15		344	(8)

Besides the gradual decrease due to the progress of the season there is a large fluctuation which must be partly attributed to an elongation of the cap, partly to its eccentric location. Without eliminating these two effects no conclusions can be drawn as to the regularity of the melting process; it would be possible to accomplish this by combining simultaneous observations made at observatories of widely differing terrestrial longitudes.

Graff,²² from visual estimates made at Hamburg-Bergedorf and corrected only for elongation of the cap, finds considerable fluctuations in the size which he represents by a curve and considers as real. Our observations, however, do not confirm these fluctuations and deviate mostly in the opposite sense. If our results are combined with those of Graff, the irregularities of the polar cap and the effects of its eccentric position are to some extent eliminated, since observations of the same date refer to central meridians differing on an average by 128° . We then obtain a fairly smooth curve, but the melting is most rapid from August 20 to September 15 and gradually slows up for the later periods.

²² *Astr. Abhandl. d. Hamburger Sternwarte in Bergedorf*, 2, No. 7, 1926.

The charts of Plates IV and V also indicate a rather steady progress in the contraction of the polar cap, and only in a few cases are any small advances in the outline of the cap noticeable; e.g. between August 21 and 22 in longitude 90° , between August 28 and 29 in longitude 50° , between September 4 and 8 in longitude 0° , or between September 22 and 26 in longitude 120° . None of these variations is too large, however, to be explained by accidental errors in the measures.

Numerous dark lanes are seen to cross the cap, especially between August 22 and September 7; measures of their crossings and starting points made it possible to fix their location with fair accuracy. They seem to be rather permanent in character and it is probably due to the greater distance of *Mars* that they do not show on the later photographs. Most likely they represent parts of the network piercing through the snow and some of them are actually later found as regular network features. This fact as well as the irregularities of the outline makes it evident that the South polar cap is melting more rapidly along the dark network markings and that these become visible even when the open meshes are still covered with snow. We must conclude, therefore, that the dark spots and lines are warmer than the light areas, and it has been

mentioned before that this furnishes support to the hypothesis that the dark markings are depressions in the surface.

As a good illustration of the melting process attention may be drawn to the gradual changes of *Novissima Thyle* (201) also called *Mitchell's Mountain*. On August 29 this region still appeared as a regular part of the polar cap; between August 30 and September 1 a fine dark lane developed dividing it from the polar cap. For about 10 days *Novissima Thyle* was visible as a brilliant white spot well separated from the polar cap (the reproductions of Plate II, figs. 10 and 12 do not show the separation as clearly as the original negative). On September 15 the spot had lost its brilliancy and appeared thereafter as an ordinary light area.

Most of the suggestions concerning the interpretation of Martian phenomena presented in this paper are, of course, not new. They were merely stated to bring the various observational facts into relationship and to indicate the personal views of the observer or his support of certain hypotheses.

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